[illegible] Power Handbooks

SHAFT GOVERNORS

THE POWER HANDBOOKS

SHAFT GOVERNORS

CENTRIFUGAL AND INERTIA

SIMPLE METHODS FOR THE ADJUSTMENT OF ALL CLASSES OF SHAFT GOVERNORS

COMPILED AND WRITTEN

BY

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CONTENTS

INTRODUCTION

THIS book is made up from material originally published in *Power*, together with some special articles which have been prepared to make it a complete handbook of the subject. The fact that nowhere in a single book can all of this material be found in a form which will be useful to the practical engineer, will, it is hoped, make the book of special interest and value.

The compiler wishes to acknowledge his indebtedness to a number of men who have contributed brief articles to *Power* and furnished him with special information regarding the various types of governors.

HUBERT E. COLLINS.

NEW YORK, September, 1908.

SHAFT GOVERNORS

I

EVOLUTION OF THE SHAFT GOVERNOR.*

THE development of the shaft governor has been a slow and steady one in this country, commencing probably in 1829, or possibly even later. It is quite probable that for a long time this governor met with little or no practical application, as it is a fact which will appear later that the period of its practical application can hardly be said to have begun before 1876. Since that time the growth in use of this governor in this country has been remarkable and many forms have been produced, all of which possess more or less merit. In England this governor seems to be scarcely known to-day, judging at least from the literature on the subject, while on the continent of Europe its use is also very limited.

My sources of information regarding the development of the shaft governor are principally to be found in the literature relating to the steam engine, which has been published from time to time during the last thirty or forty years, and in the records of the United States patent office.

The general works relating to the steam engine,

* Paper read at the meeting of the Engine Builders' Association, New York, December, 1901, by R. C. Carpenter.

with the exception of a few American works in late years, contain very little in relation to the shaft governor. So far as I can ascertain, all the works published by English authors, even up to a very late date, are entirely silent on this subject; thus, for instance, the work on the steam engine by Prof. John Perry, written in 1899, while devoting a full chapter to the subject of the fly-wheel and governor, and while describing in full the theory and various forms of the pendulum governor, is absolutely silent regarding the shaft governor. So far as I can learn from the literature which has been printed in England regarding the steam engine, any student obtaining his information from such books would know nothing whatever of the structure of the shaft governor.

The French writers on the subject of the steam engine do give considerable information relating to the subject of the shaft governor; the governor is, however, invariably described as an American invention which is used on certain American engines, and one obtains the idea from such a description that the governor is little used in France.

American books relating to the structure of the steam engine published twenty-five years ago entirely neglect the existence of such a governing device, and it seems quite probable that although the shaft governor was used twenty-five years ago to a very limited extent, it had not, at that time, made a sufficiently strong impression on writers as to lead them to consider that it was a practical device. As illustrations of this kind, we note a few instances. Thus, Knight's

Mechanical Dictionary, published in 1877, is a work devoted to explaining the structure of various machines and prime movers, and has never been surpassed or even equaled in its particular field. This work describes in detail the structure of a large number of governing devices and presents a full-page illustration showing the forms of governors supposed to be of practical value. (Fig. 1.) You will notice that some twenty-three different forms are shown, all, however, of the type known as the rotating or swinging pendulum governors, and none belong to the class which it is the object of my paper to describe. In Appleton's Encyclopædia of Applied Mechanics, published in 1878, and edited by the ablest corps of specialists ever employed at that date in this country, is a very full and complete article on the steam engine, but it makes no reference whatever to the use of the shaft governor, which was perhaps inexcusable at that date, as a shaft governor was exhibited at the Centennial Exposition in 1876.

The oldest book which I have in my library containing references to the shaft governor is "Steam Using; or, Steam Engine Practice," written by Prof. Charles A. Smith, of St. Louis, in 1885. In this work are published detailed drawings of a Westinghouse engine, and also a Buckeye engine, and each is shown with a shaft governor. I have no information at hand which enables me to state the earliest dates at which these companies commenced the building of shaft governors on a commercial scale, nor am I certain but that other engine companies introduced the

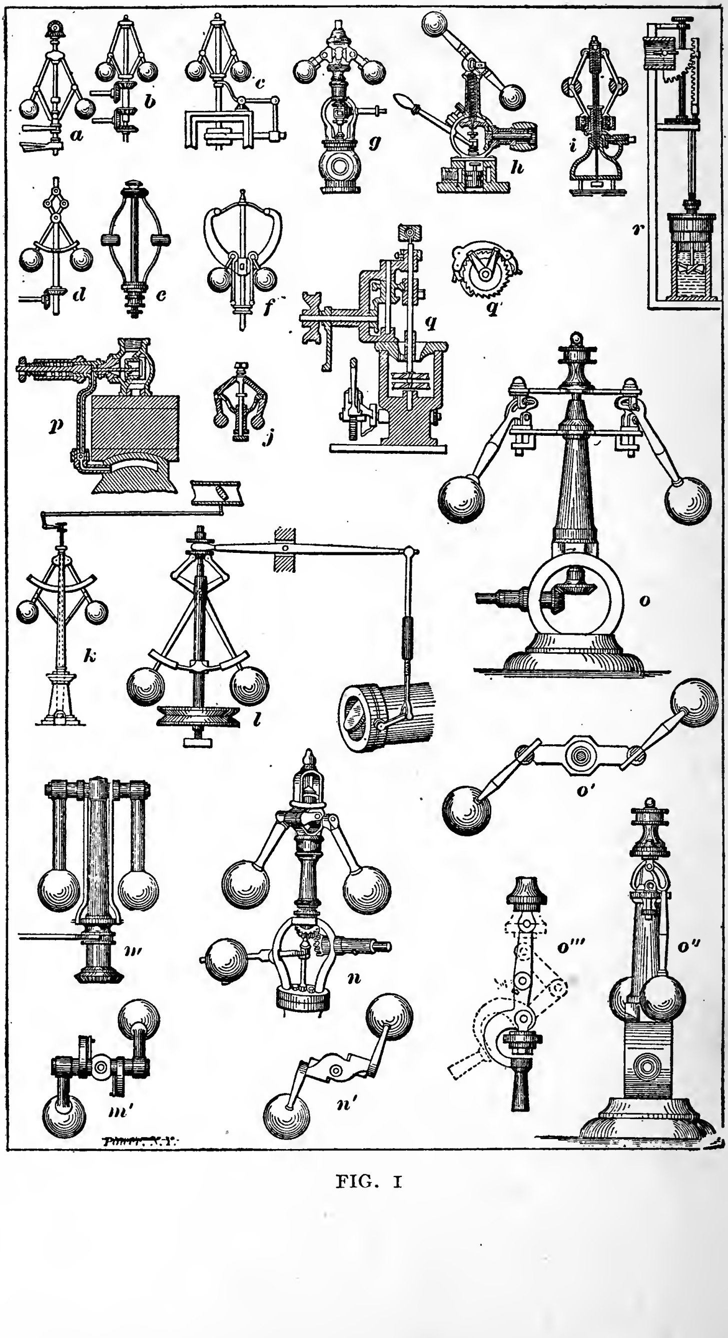

FIG. I

use of the governor at a somewhat earlier date. Views of these governors as given in Professor Smith's work are shown in Figs. 2 and 3. At the Centennial Exposition at Philadelphia, held in 1876, Prof. John E. Sweet showed an engine fitted with a shaft governor which had been built under his supervision by stu-

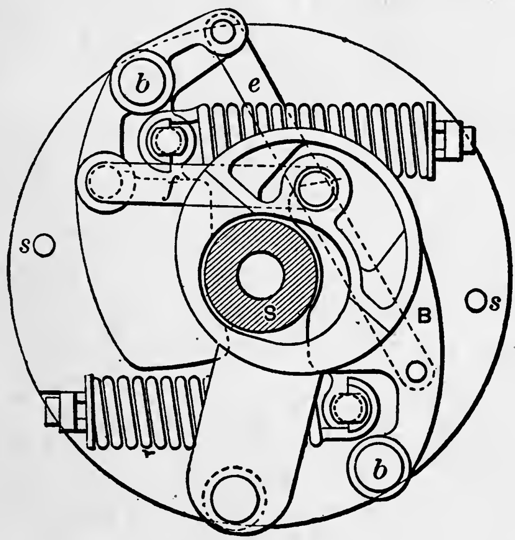

FIG. 2

dents in the shops of Cornell University. This exhibition seems to have been the inspiration which resulted in the construction of the shaft governor by many manufacturers, and the governor shown (Fig. 4) was the pioneer in the later period of development of this important invention.

This was not the first engine constructed by Professor Sweet, but was, I believe, engine No. 3. This Centennial engine is still preserved in the Museum of Sibley College, although the original governor was long ago

removed. The original governor was temporarily removed in 1889 to carry on some experimental work with governors of a different design on the same engine. Some of the parts of the governor were broken and it has never been possible to restore them in the original condition. The shaft governor on the Centennial engine was very different in construction from the later

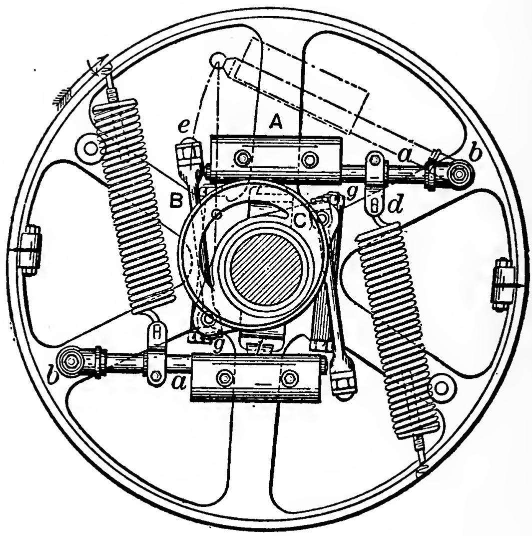

FIG. 3

ones designed by Professor Sweet and from the one now used on the Straight Line engine. The valve-rod was connected to an eccentric through the medium of a geared disk.

In later constructions of the governor applied to the Straight Line engine, the valve is connected to a swinging eccentric by link motions.

My study of the literature of the subject would in-

dicate that the shaft governor is at least, so far as its practical application is concerned, strictly an American invention, and furthermore, this invention has not been introduced to any great extent, even at the present time in Europe, while in England its use is so limited that English writers of text-books have not considered it of sufficient importance to merit any

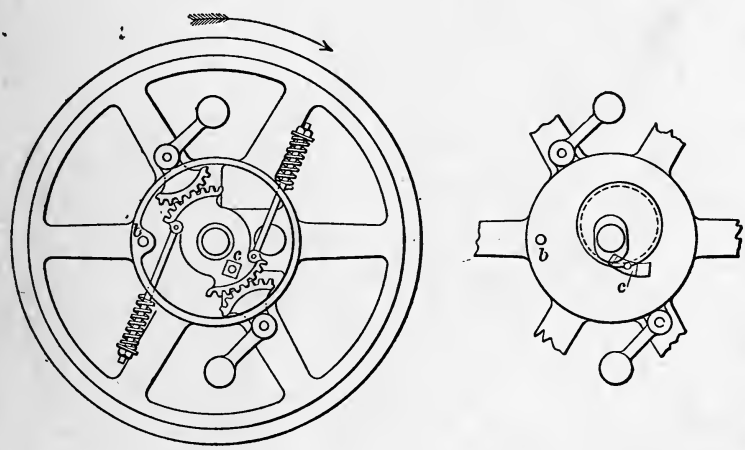

FIG. 4

mention. In this country the steam engine governor has followed the course of every great invention in its development; it has been developed, not by a single person or as a single invention, but rather by the slow and tedious process of experiment and practice. As in the steam engine itself, we find, doubtless, first a period of speculation, during which time theoretical investigations were made and patents taken out, and this period probably extended until about 1870; then comes a period of application, beginning in a small

way perhaps with 1870 and extending through the next fifteen years, during which time numerous applications of various forms were made, tried with greater or less success, modified and improved until finally a high degree of perfection has been reached.

The earlier form of governor and the one which is almost exclusively used in England and other European countries to-day was invented by James Watt, or at least adapted for use on the steam engine by Watt.

It is hardly probable that Watt ever considered himself as the inventor of the governor for regulating the speed of an engine, for the reason that I do not find this invention claimed in any of his patents and, judging from the character of the claims made in his numerous patents, Watt was not the kind of a man to omit protecting himself for any of his inventions.

In the life of Watt, by Muirhead, it is stated that for the purpose of regulating the speed of the engine Mr. Watt tried various methods, but at last fixed upon what he called the "governor," consisting of a perpendicular axis turned by the engine; to a joint near the top of this axis is suspended two iron rods carrying heavy balls of metal at their lower ends, in the nature of pendulums. When this axis is put in motion by the engine the balls recede from the perpendicular by the centrifugal force, and, by means of a combination of levers fixed on their upper end, raise the end of a lever which acts upon the spanner of the throttle-valve and shuts it more or less according to the speed of the engine, so that as the velocity augments the valve is shut, until the speed of the engine and the opening

of the valve come to a maximum and balance each other. The application of the centrifugal principle was not a new invention, but had been applied by others to the regulation of water and windmills and other things; but Mr. Watt improved the mechanism by which it acted upon the machines and adapted it to his engines.

Such, says M. Arago in describing Mr. Watt's application to the steam engine of the governor or regulator by centrifugal force, was its efficacy, that there was to be seen at Manchester a few years ago, in the cotton mill of Mr. Lee, a man of great mechanical talents, a clock which was set in motion by the steam engine used in the work, and which marked time very well, even beside a common pendulum clock.

The principle of action of the simple governor of the revolving pendulum type can be expressed by an equation as follows:

$$h = \frac{gr^2}{v^2} = \frac{g}{4n^2\pi^2}$$

from which

$$n^2 = \frac{g}{4\pi^2 h}$$

$$n = \frac{1}{2\pi}\sqrt{\frac{g}{h}} = \frac{constant}{h}$$

In this equation n equals the number of turns per second, v the velocity in feet per second, r the horizontal projection of the arm of the pendulum, h the vertical projection of the arm of the pendulum, g the force of gravity. These equations are well known and the ex-

planation of their derivation can be found in any treatise on the subject. It is noted that the position of the governor balls which are determined by the quantity *h* does not vary with the speed of the engine which is represented by the smybol n, but varies with the square of the speed of n^2, consequently a governor of the simple pendulum type cannot be made so as to give a perfectly uniform motion without some change in form or construction not known to Watt. To make the revolving pendulum isochronous in its action many devices have been brought out, and while these have in a great measure improved its action, none of them have been entirely successful. The pendulum governor has been much improved by arranging it to lift a weight and also by crossing the arms of the pendulum and arranging their point of suspension to one side of the axis. By these arrangements the distance passed through by the moving parts of the governor becomes very nearly proportional to the change in motion of the engine. These governors have also been constructed so as to utilize the force of springs instead of that of gravity to counteract the effect of the centrifugal force.

The revolving pendulum governor has usually been constructed to regulate the speed by being attached to a throttle-valve in the steam-pipe, which was opened or closed as desired. It has, however, been employed in a few cases to regulate the motion of the engine by changing the travel of the steam-valve through the medium of a link motion, and in the drop cut-off class of engines to regulate the speed by unlocking the valve

mechanism so as to permit closing, as in the Corliss type of engine.

Where the regulation is accomplished by throttling the steam supply, poor results are generally obtained for reasons entirely independent of the action of the governor, since necessarily more or less time must elapse before the proper amount of steam to give the desired speed can be made to pass through a throttled orifice. The throttling governor as usually constructed in this country has not been of the highest type of workmanship, nor has it accomplished all of the results in regulation which would have been possible with governors of its type and class, made with better design and workmanship.

The formula to which reference has already been made does not consider the retarding effect of friction. There is perhaps nothing so important in its effect on results of regulation as friction, which always acts to resist any moving force; it tends to prevent the governor balls from moving to their true position whether the motion of the engine is too fast or too slow, and consequently it becomes responsible for irregular action of the governor and for much of the imperfect regulation. It is, however, important to note that the revolving pendulum governor is not theoretically perfect, and aside from imperfections of construction and design it cannot be made to give a perfectly uniform motion to the engine.

In the shaft governor we find in every case a weight supported by an arm or arranged to move in guides connected to a revolving fly-wheel, so that the centrif-

ugal force tends to throw it away from the center. A spring is employed to counteract the effect of centrifugal force and is so arranged as to restore the weights to the normal position when the engine comes to rest. In this governor the centrifugal force tends to throw the weighted portions outward and toward the circumference of the revolving wheel, whereas the spring tends to draw the weight inward and counteracts the centrifugal force, holding the governor in such position as to maintain uniform speed. By properly proportioning and arranging the weights and the spring, it is entirely possible to make a governor of this class so that its parts will move directly proportional to any change of speed of the engine, and consequently it will take such a position as will tend to keep the motion perfectly uniform regardless of other conditions. In other words, it is possible to make a governor of this class which will give theoretically uniform motion.

The tendency of a moving body to continue its motion uniformly has been well known since the time of Sir Isaac Newton and is generally known as the "principle of inertia." It has been recognized from the earliest times in the art of steam engine building that heavy fly-wheels conduced to uniformity of motion because of the inertia of the parts. This uniformity of motion is a well-known function of the weight of the fly-wheel. Consequently it has been the practice for years to use heavy fly-wheels where a uniform motion is desired, and even at the present time we have found no system of regulation which entirely permits us to do away with that produced by the inertia

of heavy weights. The irregular motion produced by the intermittent action of the steam on the piston can be very largely reduced to a uniform action by the use of an extremely heavy fly-wheel and the minute variations in speed can probably be controlled by no other method. As the engine is made to revolve at a higher speed the impulses are made at greater rapidity and consequently a fly-wheel of smaller weight can be employed for the same degree of uniformity of motion. The shaft governor could, of course, be connected to a throttle of a steam engine and would in that case produce results superior to any of the revolving pendulum governors, but such an application has, so far, as I know, never been attempted. The governor has been universally connected through the medium of rods and links directly to the main or auxiliary valve which regulates the supply of steam to the engine. The advantage gained by this construction is that of admitting steam of full power behind the piston at each stroke, and thus giving the full benefits of expansion of the steam in its work.

This advantage is great and will result under usual conditions in a marked improvement in economy, as compared with a throttling engine otherwise the same. I had an opportunity once of testing two engines, one automatic, the other throttling, both in excellent condition, doing alternately the same work. The results, which I do not have here in full, showed slightly over 12 per cent. in favor of the economy of the automatic engines, yet the conditions I considered as favorable as possible for the throttling construction.

The shaft governor has proved itself to be especially adapted for engines moving at a comparatively high speed of rotation. The results produced in the way of regulation in engines of this type have been in some instances simply remarkable, as it has been found entirely possible to produce a governor which would hold the engine to the same number of revolutions per minute, whether the engine were running light or loaded, or whether the load were suddenly or slowly applied or removed.

The shaft governor, revolving as it does with the shaft of the engine, is affected by the inertia of its particles in the same manner as the revolving fly-wheel. The governor parts may be arranged so that this inertia effect may tend to make its action quicker, in which case the regulation of the engine would be improved, or it may be arranged so as to have the reverse effect, in which case the regulation of the engine would be worse than before. This effect of inertia on the part of the governor and its use for improving the regulation was not recognized until the shaft governor had been pretty well developed, but a study of the drawings of some of the early types of governors show that they were constructed and operated in such manner as to have the full benefit of inertia to aid in the regulation. This seems to have been notably true in the case of the governor shown by Professor Sweet at the Centennial Exposition.

The records of the American Patent Office in reference to the shaft governor are of much interest, but time will not permit any extended reference to these

records. A few of the earlier patents are, however, considered of so much importance that drawings are submitted and quite full references are given. These early patents do not, probably, represent any practical application, but they are interesting as showing a complete understanding, not only of the theory of the shaft governor, but of methods of application to practical work.

The earliest reference which I have been able to

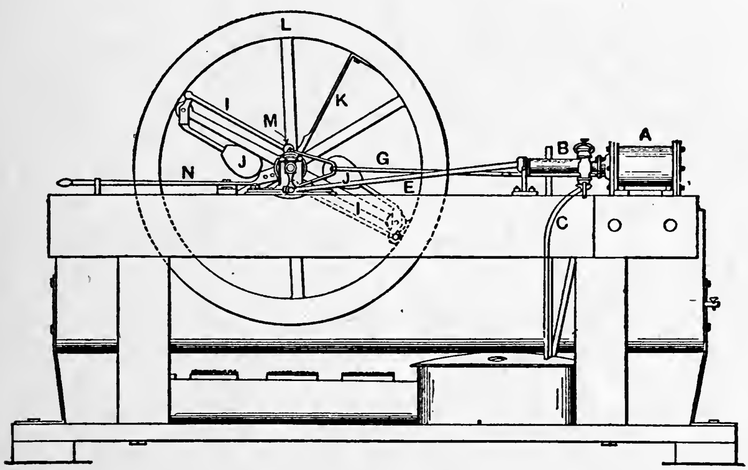

FIG. 5

find to the shaft governor is shown in a patent granted J. D. Custer, June 21, 1839 (Figs. 5 and 6). From these it will be seen that it consisted of two balls or weights symmetrically disposed in the fly-wheel and in gravity balance and pivoted to radial arms and connected by links with the eccentric in such a manner that the action of the centrifugal force would cause the balls to fly out, and this action would twist the

eccentric on its center so as to reduce the travel of the valve. The action of the centrifugal force was opposed by a flat spring. The drawing indicates a form of a governor which should have been of practical utility, but I have not been able to find, however, that the governor patented by Custer was ever put into

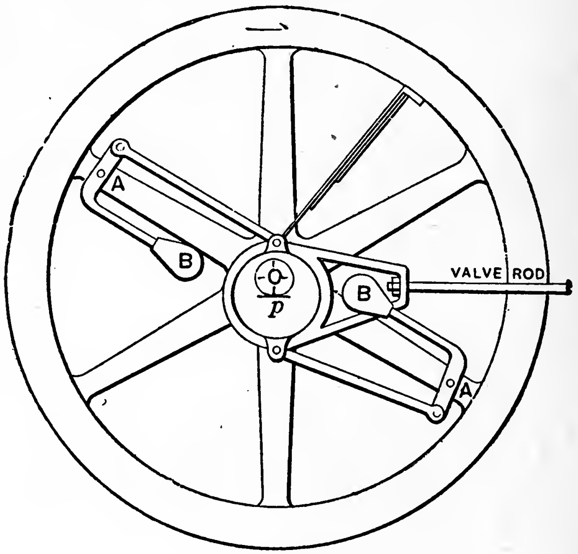

FIG. 6

practical use. It is quite certain that this invention did not produce any great change in the art of building steam engines, as the shaft governor seems to have been practically unknown for nearly a third of a century after this date.

The next governor patent to be granted was to Lewis Eikenberry, of Philadelphia, April 1, 1862 (Fig. 7). The patent was given principally for an improvement in variable cut-off valves, in which the valve motion

was regulated by use of a cam. The shaft governor shown was of peculiar type, in which the pivots or the arms to which the balls were fastened were in the plane of the revolving wheel so that the centrifugal force carried the balls into a position at an angle to the plane of the wheel and nearly parallel to the shaft.

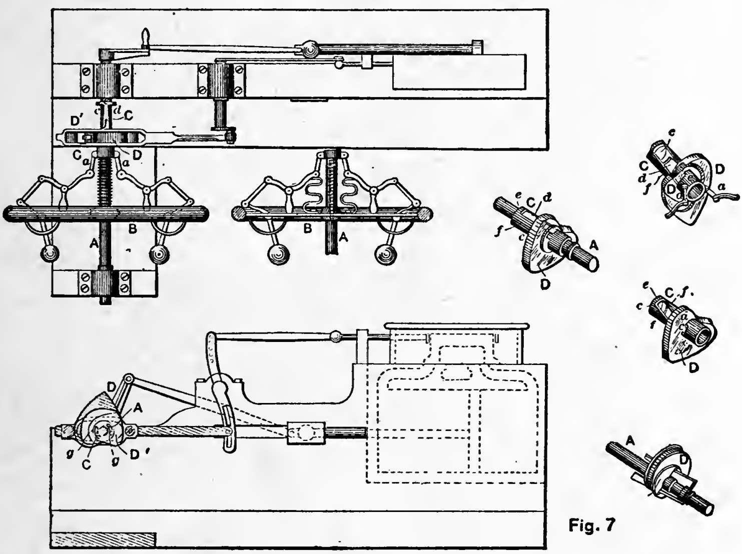

FIG. 7

This form of governor should have been efficient and effective, but it doubtless would have proved not practicable to apply in numerous cases. The next governor patent was granted to Joab H. Wooster, August 20, 1867, of which no picture is shown, of the same general type as that granted to J. D. Custer; in this patent, however, the eccentric was arranged so as to fit loosely upon the shaft and was connected to the governor in such a manner that it would swing past the center of

the shaft, thus changing the lead of the valve. The construction shown in the patent granted for this governor would probably have resulted in a partial success, but I have not been able to find evidence which would show whether or not this governor was put into practical operation.

The next patents in order, to which we will refer only by name, were as follows: Samuel Stanton, Newburg, N. Y., July 14, 1868; D. A. Woodbury, Rochester, N. Y., May 31, 1870, and also September 27, 1870. In the latter patent, which shows a governor used later in the well-known Woodbury engine, a distinct statement is made in the specifications regarding the effect of inertia on the parts of the governor, and the arrangement is made so that inertia, as well as centrifugal force, is employed for governing purposes.

The next patent in order was granted to Joseph W. Thompson, Salem, Ohio, July 15, 1872, and which, with a later one granted April 27, 1875, and still another on January 18, 1878, forms the basis of construction which has been used so long and with such excellent results in the Buckeye engine.

In chronological order patents were granted to John C. Hoadley, October 28, 1873, and March 17, 1874, for shaft governors, both of which were practically used on the Hoadley engine.

From this time on patents on shaft governors are exceedingly numerous and cover different forms of mechanical devices and different methods of application of mechanical principles. The improvements of a later date are generally of a nature which resulted

in simplifying the construction, reducing the number of working parts, lessening the friction and thus making the governor more perfect in its action.

The shaft governors can be divided into two classes with respect to the motion of the valve, namely:

Class I, in which the eccentric is rotated or twisted around the shaft. The travel of valve is changed without change of lead.

Class II, in which the eccentric is mounted on a disk with a center different from that of the fly-wheel and is swung in the arc of a circle across the center of the shaft. The travel of the valve is changed with change of lead.

For both the above classes of valve-gear the governor can be essentially of the same character, hence the above distinction does not necessarily indicate a structural difference in the governors.

Neglecting the difference of swinging or rotating eccentric, governors can be divided into three groups, depending on structural differences.

These groups are as follows:

I. Governors with two weights in gravity balance, as already shown in early examples in the Custer, Buckeye and Westinghouse governors.

II. Governors with a single weight in gravity balance, with eccentric and governor mechanism.

III. Governors with single arm in partial gravity balance which carries inertia weight, centrifugal weight and eccentric.

All the above classes can be operated so as to have regulation assisted or retarded by inertia and can

probably be connected to rotating or a swinging eccentric as desired.

A very good illustration of a shaft governor of the first class is shown in Fig. 8. The eccentric is mounted on a plate *G*, pivoted at *P* and is connected to *E B*, No. 1, and *E B*, No. 2, by connecting rods, in such a

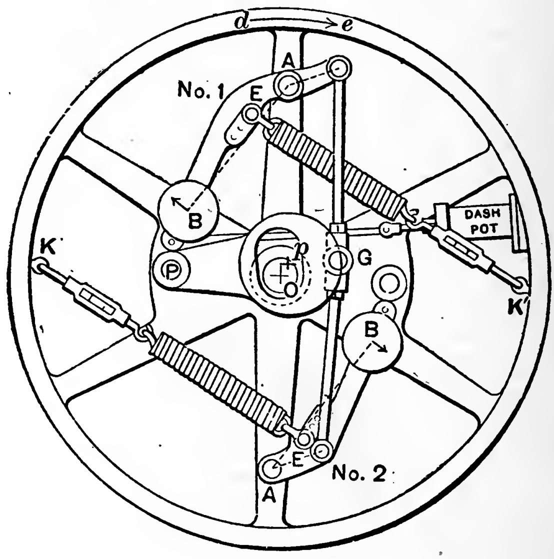

FIG. 8

manner that the action of centrifugal force in throwing the weights *B B* outward causes the center of the eccentric to swing toward the center of the shaft. The springs pivoted at *K* rock against the centrifugal force and hold the weights in a determinate position for each speed. The dashpot simply restrains the motion when too rapid and tends to prevent racing. There are numerous governors in this class.

Fig. 9 represents a notable illustration of a shaft

governor in Class II. This governor, although consisting of a single weight, is still in gravity balance. Its advantages over those in Class I are a less number of working parts, simpler construction and less friction.

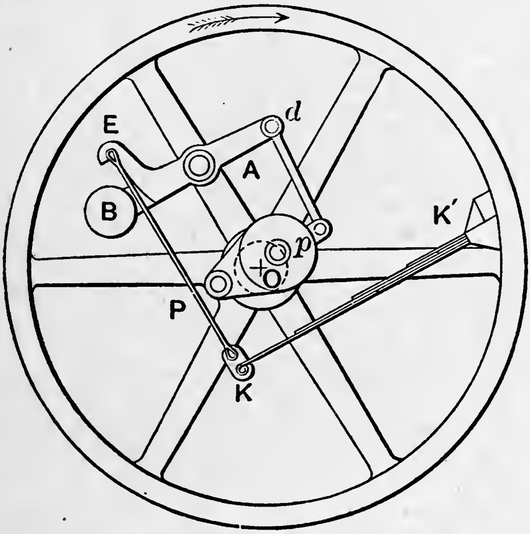

FIG. 9

The governor is used on the Straight Line engines and one or two others, and is the latest design of Prof. John E. Sweet.

Fig. 10 represents a governor in Class III. This governor was designed by different engineers and the patents are now owned by Mr. Frank Rites. It is now in very extensive use in the United States. This governor has a single moving part mounted on a single pivot. It is designed to take full advantage of inertia, and is so nearly in gravity balance that no bad results in regulation were ever shown by defects in balancing.

The friction in this governor can be reduced to a minimum and the results are great sensitiveness and wonderful regulation under adverse conditions.

The accompanying table gives a list of United States

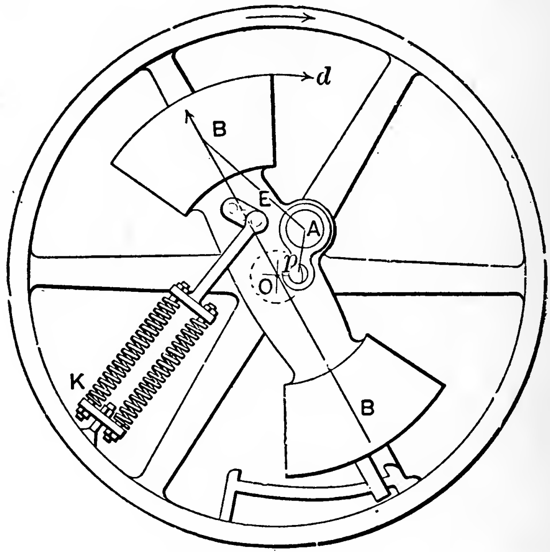

FIG. 10

patents for improvements in the shaft governor granted previous to 1880, in all only twenty-nine, of which five were granted before 1870, and twenty-five between 1870 and 1880. Since that date the patents have been numerous.

EARLY LIST OF U. S. PATENTS FOR SHAFT GOVERNORS

Patents Granted Prior to 1880

1839	June 21	1,179	J. D. Custer,
1862	Apr. 1	34,821	
1862	Apr. 16	38,055	L. Eikenbury, Philadelphia, Pa.
1867	Aug. 20	67,936	Joab Wooster, Strykersville, N.Y.
1868	July 14	80,025	S. Stanton, Newburg, N.Y.
1870	May 31	103,698	D. A. Woodbury, Rochester, N. Y.
"	Sept. 27	107,746	" " "
1872	July 16	128,986	J. W. Thompson, Salem, O.
1875	April 27	162,715	" " "
1873	Oct. 28	144,098	J. C. Hoadley, Lawrence, Mass.
1874	Mch. 17	148,560	" " "
1875	June 29	164,917	" " "
"	" 29	164,942	G. C. Suiss, " "
"	July 20	165,744	H. S. Maxim, Brooklyn, N. Y.
"	Aug. 31	167,225	Corbitt & Campbell, Milwaukee, Wis.
"	Sept. 21	167,835	J. Felber, St. Louis, Mo.
1876	Jan. 11	172,116	Hall & Whitteman, Hasma, N. Y.
"	Sept. 5	181,927	G. F. Ernst, St. Louis, Mo.
"	May 11	184,443	G. E. Tower, Annapolis, Md.
1877	Jan. 9	187,116	Cosgrove, Faribault, Minn.
1878	June 18	204,924	Thompson & Hunt, Salem, O.
"	July 30	206,500	H. Tabor, Corning, N. Y.
"	Aug. 6	206,792	C. B. Smith, Newark, N. J.
"	Sept. 3	207,607	D. O. Ladd, Chicago.
"	" 3	207,608	" "
1879	Jan. 14	211,309	L. H. Watson, "
"	" 14	211,335	C. S. Locke, "
"	Mch. 18	213,395	G. H. Cobb, Palmer, Mass.
"	Nov. 4	221,296	F. Fosdick, Fitchburg, Mass.
1880	May 25	227,967	C. V. B., San Francisco.
"	Aug. 17	231,228	W. Johnson, Lambertville, N. J.

The limits of this paper do not permit an opportunity for further discussion of the various forms of shaft

governor, or of its theory and method of action. The account of the development is imperfect, for the reason that the sources of information available were neither numerous nor exhaustive, but it is to be hoped that various members of the association will supplement the facts gathered together and presented in this short paper, with data relating to the development of the governor, while it is still fresh in mind.

There are many reasons for obtaining this information fully and in detail while there is an opportunity. Such investigation as made indicates that the shaft governor as we know it to-day is essentially an Amercan invention, conceived, developed and perfected in this country.

The importance of this system of regulation is so fully recognized as to need no argument in its favor, and while at the present time the shaft governor is used only in an experimental way on certain classes of engines, yet the few experiments which have been performed indicate that its field is not limited to any great extent by speed requirements, and it seems reasonable to suppose that a period of development may extend its use to include not only all classes of steam engines, but gas engines as well.

The demand for close speed regulation came with the invention of the incandescent.

II

GENERAL DEFINITIONS AND RULES

Before going further into the subject of governors it may be well to fix in our minds some of the definitions of terms used in reference to them, and already referred to in Chapter I.

Centrifugal force is that force which tends to fly from a center. A familiar illustration of it may be noted in swinging a weight, attached to a cord, about the head. The longer the cord the greater the force required to keep it revolving.

Centripetal force is force which always tends toward a center; the opposite of centrifugal force.

Inertia is that property of matter which tends to keep it at rest when resting, and, when in motion, tends to keep it moving in a straight line. It is this force which makes it difficult to start a heavily loaded wheelbarrow, and also to bring it to rest again when well under way.

Isochronal means relating to equal periods of time. This term is sometimes used in reference to shaft governors. The principal difference between the two general classes of governors, pendulum, and shaft is in the action of the forces which control them. In the pendulum governors there are the two forces, centrif-

ugal and gravity, which are equal at only one point of the operation of the same. In the shaft governor the force of inertia, or centrifugal force, is at all times opposed by an equal amount of spring-force. The weight-force increases as the weights move from the center, the spring-force also increases as the springs are extended by the weights.

When a governor is "sluggish," the speed falls far below its rating, and is not acquired again quickly, perhaps not at all. The weight-force is greater than the spring-force; the former must be decreased to get sensitiveness, and the latter altered to get the speed.

When an engine simply "speeds up" and must be checked on the throttle, either excessive friction in some of the parts exists or the spring-force is too great. Decrease the spring-tension to remedy this.

When an engine "races" or hunts," the two forces are unbalanced and are alternating rapidly in overcoming each other, causing the engine to alternate in speed within a certain range. Giving less tension on springs to decrease sensitiveness and changing weight to get the speed, is the remedy.

Racing may also be caused by friction of parts or other local troubles, as will be shown later in this chapter. There is, however, a noticeable difference between racing caused by over-sensitiveness and friction. When it is caused by the spring-tension alone the changes in speed will be rapid and even, within a certain range. When caused by friction the weights will stick on their inner position until the speed developed is so high as to throw them out with a noise;

or, when the engine is above speed, they will stick where they are until the speed is reduced enough for the springs to draw them back again.

The speed at which they will regulate, and the sensibility of the shaft governors depend principally on the following conditions: (1) Tension of springs; (2) the distance from the pivot where they are attached to the weight, or weight-arms; (3) the amount of weight; (4) the distance of weight from fulcrum.

Examples of, and Search for, Trouble

All of the well-known makes of shaft governors at the present date, of whatever class they may be, are thoroughly tested, regulated, and set by the makers, so that in the start they are turned over to the operating engineer regulating to within a certain range of percentage of speed called for, and are as perfect as they can be made. The difficulties that arise after being in service some time have a cause and a remedy.

Once a governor is perfected and running there is no reason why it cannot be brought back to that condition after it has been lost. If this fact is kept in mind, by perseverance the trouble will be readily found; often it is a very slight one, so small as to be easily overlooked. An engineer has been known to take a spanner-wrench and give the valve-rod gland a half turn to tighten it up, and so caused his engine to run away. Another had his engine, with a Sweet Governor, race because a single very small grain of gravel got between the band which connects the spring

and weight-arm and the weight-arm itself. Again a pinching cap on one of the fulcrum-pins or a slight burr on a valve-rod has caused trouble in a governor. The slightest thing should not be overlooked. Dry pins are often the seat of trouble; and a governor, to be properly attended, should be oiled as regularly as any other part of the engine, and once in a while all pins and bearings should be taken apart and cleaned.

When a search for trouble begins nothing should be neglected, from the governor-eccentric to the farthest edge of the valve in the valve chest. Disconnect the eccentric rod or rods, as the case may be, from the governor-eccentric, and remove or release the spring or springs from the weight-arm or arms.

Then move the weight-arms in and out on their travel from inner to outer positions. Most of the shaft governors made on engines from 5 H. P. to 1,000 H. P. are so counterbalanced that when thus operated one man should be able, on the smaller makes, to easily move the parts in and out with one hand, and, on the larger engines, with both hands, but he should never use a bar of any kind.

If they do not move so freely as to permit this the trouble is caused by dry or cut pins, pinching caps, bent rods or links making pins bind, pinching or dry eccentric-straps, or eccentric binding (in some instances between a bearing and governor-wheel hub) or sometimes gummed oil and grit cause it.

If the governor is free and in perfect condition disconnect the valves from the rockers or valve-rod slides,

as the case may be. Then look for dry surface of pins or bearings or slides, bent rods and other like conditions. This done, see that the valve stems are straight and true, and in line with their connections, also that their bearings do not bind and are not dry. See whether they are burred or worn small in stuffing box so that the packing binds it when pulled up tight, and whether the packing is old and dry.

Then look into the steam chest. See if the valve is set properly and if it leaks, or if the pressure-plate binds. Often an engineer forgets that proper valve setting is as essential as it is to have the governor free and well lubricated. An illustration of the fact that the valve setting must be carefully reckoned on is shown by the following experience:

A 500 H. P. cross-compound engine running condensing in a certain power house near New York City, began at one time to race and speed up very badly, and used much steam for no apparent cause. The steam pressure was 120 lbs. and the receiver pressure was from 45 to 70 lbs., which in itself showed something wrong with the valves, though the trouble was attributed to the governor.

This engine was vertical and had four gridiron valves to each cylinder, which allowed each valve to be set independently. The valves had small lap and the steam was admitted over the edges of the valves nearest the end of cylinder. An examination showed that the top steam-valve had been shoved up so that a late opening of valve occurred, and when the valve was supposedly lapped there was reopening of the

same on the opposite edges. This allowed the steam to blow through and on into the receiver, raising the receiver pressure and exerting a back pressure on the up stroke almost equal to the initial pressure on the opposite side of the piston. This made the H. P. cylinder inoperative, and the L. P. cylinder was doing more than its rating, thus unbalancing the engine and putting it beyond the control of the governor.

One turn on the valve-stem, drawing the valve into place, corrected all the trouble.

In one instance a large engine of well-known make ran for some time giving bad service — regulating badly. Finally it was discovered that the pressure-plates were so weak that they sprung in and pinched the valves while running, but were always apparently free when tested at other times. New and stiffer pressure-plates remedied this.

In cases where the direction of rotation of an engine is changed from running over to running under, or *vice versa,* the eccentric, and all governor parts, must be changed in their positions. The various makers give instructions for these changes, but the essential points to know in connection with quick changes are these: The pivoted ends of the levers should always lead, and the weights follow, the desired direction of rotation, and be so placed that when the weights move out the eccentric will be either advanced in the direction it will run for governors of the first class, Chapter I, or thrown across the shaft center in governors of the second class. Lack of a knowledge of this is sometimes a very serious source of trouble,

and these facts should be carefully stored in the mind, when a search for trouble begins.

At times it seems impossible to get enough spring-force to obtain proper adjustment of the governor, either from too long a spring or a weak one, more commonly the former. The remedy is to cut off one or two coils of the spiral spring until the desired effect is obtained. The best way to make such a cut is to spread the coils by driving a chisel between them and keeping it there until a score can be filed all the way, or at least three-fourths of the way around the springs; then remove the chisel from between the coils and finish the break with the chisel, laying the coil on an anvil or some heavy ridged surface. The flying coils, when they have parted from the rest, should be guarded against.

When we have a governor such as is described in the third group, Chapter I, we have the force of inertia to deal with in addition to the spring and centrifugal force.

In this type of governor, the weight on both the spring and free ends of the bar is inertia in effect, but changes of weight on one end has the opposite effect to the same change on the other end.

Changing the spring in this governor gives the same results as with all governors.

Changing the weight on the free end of these governor arms gives the same results as with the others.

A change of weight on the spring end of these arms gives the opposite effect to a like change on the other end. No radical change in weight of this class of

governor should be attempted without consulting the builder.

Sometimes, with the governor properly adjusted and free from friction, the engine will still speed up. This is caused by leaky valves or from insufficient steam-lap to cover the parts at all points of the engine-stroke, when the governor-weights are at the outer extreme of their travel. To test for this latter defect, remove the governor-spring or springs and block the weight-arms to their outer position, and then, while turning the engine one complete revolution, observe whether the steam edges or steam-valve covers the ports at all points of the revolution. If they do not, the valve setting must be changed to accomplish this.

The rules of action laid down in this chapter apply generally to all makes of shaft governors. Where radical changes are to be made, the builders should always be consulted, and the knowledge that each understands best how to operate his own special design of governor has impelled us to insert in the following chapters the rules of procedure, or instructions, of the builders, for use with each design named. In the study of the succeeding pages, the reader will note where these general instructions apply to the individual cases.

The two classes of governors as specified in Chapter I will be covered in these individual cases, but in the event of the operator not having an engine named individually in these chapters, the general rules of this chapter will no doubt cover the case.

III

ADJUSTING THE RITES INERTIA GOVERNOR*

The inertia governor, invented by F. M. Rites, is now regularly used on engines made by considerably more than one hundred different manufacturers. It is thus the most commonly used governor for high-speed engines, and is already being adopted for use on slow-speed engines as well, either in place of the ball governor for Corliss valve-gears, or as a shaft governor for the large four-valve medium-speed engines now coming into general use. The principles governing its action, and the various ways of adjusting this governor to produce desired results, are of interest to every stationary engineer.

The Rites governor consists of a single piece of cast iron in the general form of a bar, mounted at right angles to the engine-shaft and carried on a pivot-pin parallel to the shaft. At a suitable point on this bar is provided a wrist-pin to which the valve-rod is connected, or if the governor is placed elsewhere than at the end of the engine-shaft, an eccentric is used instead of the pin. A spring opposes the inertia force of the bar.

* Contributed to *Power* by R. E. Cahill and S. H. Bunnell. This governor is in the second class of the third group, Chapter I.

The accompanying sketch (Fig. 11) shows the governor-wheel in outline, and the elementary form of the governor-arm. Observation will make it evident that the governor-arm, considered as two heavy masses *A, B,* will tend to overtake the fly-wheel if the engine-speed is reduced, as by increase of load, and to fall

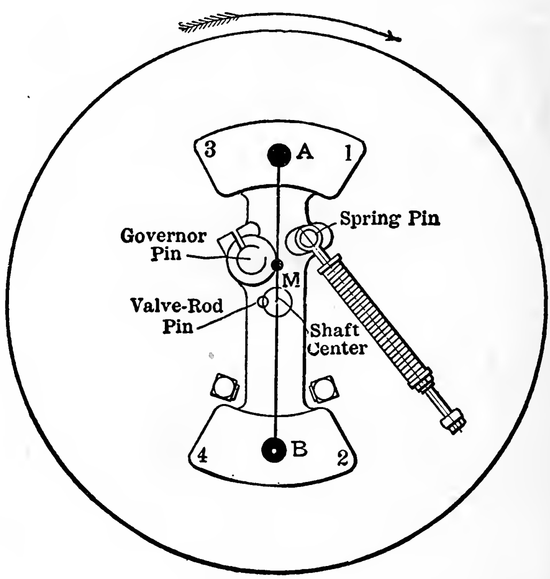

FIG. 11

behind the fly-wheel if the engine-speed is increased, as by decrease of load. It is also evident that the governor-arm, considered as a mass *M* located at the center of gravity of the whole arm, tends to swing in when the engine-speed is reduced, and out when the speed is increased. The arm therefore takes a position in which its centrifugal force balances the spring-tension (or as nearly that position as the arm stops will allow),

and moves relatively to the engine-shaft forward and inward if the engine-speed is decreased, and backward and outward if the engine-speed is accelerated.

The valve-rod pin (or the crank of the eccentric if that is used) is located nearly on the line from the arm-pivot center to the shaft-center, and distant from the shaft-center by the lap of the steam-valve when the governor-arm is in full-speed position. In practice, the governor is keyed to the shaft so that the arm-pivot pin is a little ahead of the center line of the engine-crank when at full speed. To prevent running over speed when without load the steam-lap must be great enough to give practically no opening when the governor-arm is in full-speed position, which means zero lead in this position. As the arm swings in, the lead increases, but not enough to give a proper lead in the usual running position unless the governor is set a little ahead, as described. The corresponding disadvantage is an excessive lead at late cut-offs.

The governor is designed by the engine builder in accordance with certain emperical rules developed by Mr. Rites from extended experience. It should have power enough to actuate the valves of the particular size of engine for which it was designed, and should only need adjustment in some of the several ways provided in order to meet the special requirements of any particular case. The first step in correcting faulty regulation of an engine is to determine the speed under a small load, say one-fourth of the rated load of the engine. If the speed is steady under small changes of this load, but too slow, tighten the gov-

ernor-spring; slacken the spring to decrease the speed. If the spring is not strong enough, so that screwing up further has not the effect of raising the speed, or if the spring is stretched to the limit of space allowed, one or more coils may be cut off, or any attached weights removed from the short end *A* of the arm. If the speed is not steady, but changes irregularly without corresponding change in load, look for trouble in the pivot-pin bearing — lack of oil or a cut and scored pin or bushing, and correct this first.

Next increase the load and observe the speed of the engine. If it drops more than desired, try setting the spring-pin farther toward the governor-arm pivot along the slot provided, or remove any attached weights from the end *A* and reduce the spring-tension; or add a small weight to the end *B* of the arm on the spring side, or both. Moving a weight on the end *A* from 1 to 3 has a similar effect, but in less degree.

It sometimes happens that the drop in speed cannot be overcome by the usual methods of weighting. In such cases, first making sure that the lap of the valve is sufficient, look for a hard-running valve, which, at full stroke, pulls excessively on the governor, springs the rocker-arms and connections, and by the combinations of fault causes the speed to drop. If possible, keep the load steady while counting or otherwise observing the speed. If the speed does not drop somewhat from light load to full load, the governing will probably be unsteady under quick changes, and the spring-pin should be moved out in the slot, or weight added to the short end of the arm on the spring

side. After any such change the speed will have to be brought back to the desired rate by adjusting the spring, as at first.

Next try the speed with all load off the engine, if that condition is ever likely to exist in the plant. If the speed rises considerably, the steam-valve leaks, or the steam-lap is insufficient to cover the ports entirely when the governor-arm is in the full-speed position. It is often found that a valve which apparently has the proper amount of lap will open slightly as the piston advances and allow the engine to run considerably over speed when the load is thrown off. Condensing engines will almost invariably run considerably faster without load, and it is best not to attempt to keep the no-load speed down to the exact figure, as the increased lap necessary makes the lead in the running position deficient. If the valve is decided to be too short, it is often easiest to make an offset-pin for the valve-rod, and put this in place of the regular pin in the governor-arm so as to decrease the throw at minimum travels, and thus save buying a new valve. Careful observation of the speed of the engine under different loads, and successive adjustments in the manner described, will soon bring the engine to the desired condition.

In adding weights it is well to bear in mind that a change in the weight of the governor-arm as a whole is not what is wanted, but a change in the distribution of the weight. If you find yourself about to add a weight which will act exactly opposite to one already in place, try taking off the other weight first; perhaps

none is required. If the desired regulation has been obtained by a combination of weights on one or both ends of the arm, experiment will usually prove that the same result can be secured by a single weight properly placed. It is merely a question of balancing the centrifugal force of the governor-arm against the tension of the spring. If these are exactly balanced at all points there will be no permanent change of speed from no load to full load, which is sometimes a desirable condition and is easily attained by the inertia governor; or the weight and spring-pin may be arranged so that the balance will vary at different points of the movement, the arm requiring a greater speed to hold it out against the extreme tension of the spring than to balance the spring-tension in other positions, giving an increase of speed as load decreases. By overbalancing the governor, an engine could be made to run much faster with load than without, but for safety and reliable running the full-load speed should be nearly two per cent. lower than the no-load speed.

The adjustment of speed to load as described depends on the centrifugal effect. Steadiness under change of load depends on the inertia effect, and is next to be considered. When the load is suddenly increased, the consequent checking of the engine-speed allows the governor-arm to run ahead of the wheel, carrying the center of gravity and lengthening the cutoff. If the fly-wheel is sufficiently heavy and the inertia effect of the governor-arm great enough, the engine-speed may drop only slightly. But with a free-moving governor the arm is likely to swing too

far, resulting in too late a cut-off and an increase of speed after the momentary drop as the load first came on, followed by a swing the other way as the engine overruns the governor-arm, and so on. These swings are quite regular, and very clearly shown by the voltmeter on a direct-current unit. If a sudden change in load produces two or three long swings before the engine finally steadies itself, try adding a weight to the long end of the arm, on the line through the centers of the pivot and the shaft. One swing is to be expected, but the engine should be so regulated that it will swing once up and back to the correct figure, never passing the normal speed twice for one change of load. If the speed changes too much at first and comes back too slowly, extra weight on the long end *B* of the arm is probably needed, as in the other case.

The most troublesome condition is irregularity. Engines are sometimes found to vary speed unaccountably, perhaps suddenly, and at odd intervals. Sticking at the pin is a common cause of this, but too free a pin may possibly allow the governor to float under insignificant impulses and produce a similar effect. The governor-arm is unbalanced against gravity, and if the engine is run at too slow a speed it may fall forward somewhat during half the revolution and backward during the other half, making the cut-off too long on one end, or irregular in successive strokes. Sometimes the gravity effect combines with valve-rod friction or inertia and makes the motion kick the governor so that the valve-gear moves with peculiar jerks. A simple brake, as a piece of flat spring bear-

ing on the arm, or a dash-pot, may be the easiest means of controlling this. A large, stiff governor-pin introduces just the necessary element of friction to make the governor stable, and is thus desirable for other reasons than strength.

A common cause of complaint with large governors is hammering on the stops in starting or shutting down the engine. This can usually be overcome by moving attached weights and noting whether hammering is inrecased or diminished. Usually the proper change is in the direction of adding weight on the spring side of the arm and increasing the spring-tension, though it may be necessary to add weight at both ends. It is a peculiar fact that friction in the valve-gear operates to help the governor-spring, so that an engine may be speeded up several revolutions by excessively tight valve-stem packing or any similarly acting cause. It is well to look over the valve motion as a possible cause of any unaccountable change of speed. If a brake is used on the governor and is set up too tight, it may cause continual changes of speed through its action in checking the governor-arm as it swings out or in, and so preventing the arm from floating gradually to the proper position.

It may be necessary to adjust the governor with no other data than what can be learned by watching the switchboard meters while the engine runs in service, and applying the proper remedy for the apparent fault on the occasion of the next shut-down. It may take an hour's careful watching to make sure regarding the real action of the governor; for the only sure way is

to wait for the load to change as desired and remain constant long enough to give the engine time to settle to a steady speed, and repeat the observation until the exact speeds under several different loads are ascertained.

In conclusion, before altering a Rites' governor the engineer should make sure that the main pin and its bushings are free and properly lubricated, and that the valve has sufficient lap and runs freely. If the arm is heavy enough to drive the valve, see whether the desired governing effect can be produced by adjusting the spring; also avoid adding unnecessary weights and the consequent overstraining of springs, bushings and pins.

IV

THE BUCKEYE ENGINE GOVERNOR AND ITS ADJUSTMENTS

THE governor of this engine of which (Fig. 12) is a cut, comes in class 1, group 1, as specified in Chapter I. The following instructions are for its adjustment.

NAMES OF PARTS

The following names are given to the several details of the governor for convenience of reference.

The levers or *weight arms a a* will be called *levers* hereafter for convenience.

The weights A A are clamped on the levers.

The lever pivots b b are studs, secured to arms of the containing wheel on which the levers move freely.

The links B B couple each lever to ears on the sleeve of

The Governor eccentric C, which is free to turn on the shaft and is turned about 90 deg. on the shaft by the outward movement or *expansion* of the levers to the outer extreme of their range of movement.

The main springs F F are of tempered steel wire. They are anchored adjustably to the rim of the containing wheel by means of

The tension screws c c by which the tension is adjusted.

The spring clips d d are clamped on the levers *a a* and are provided with slots or *eyes* into which the

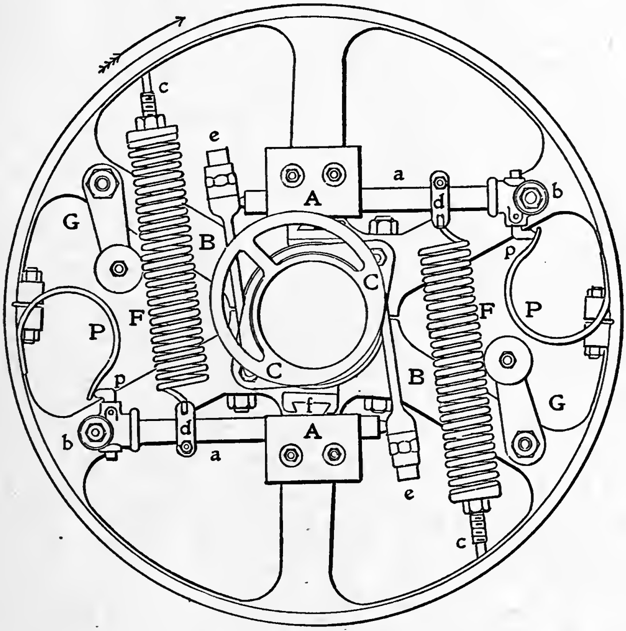

FIG. 12

springs *F F* are hooked. They may be moved along the levers and fixed in any position within narrow limits.

The lever stops f f are blocks of wood on which the levers rest when not expanded. They are held in dovetail recesses in brackets bolted to the containing wheel.

The outer lever stops e e are cylinders of wood fitted to sockets in the outer caps of the links *B B*. If the levers expand violently they strike the inner surface

of the containing wheel rim, but with proper adjustment they seldom or never touch the rim.

The auxiliary springs P P are introduced *to help the levers out* during the first half of their outward movement, when the main springs *F F have enough tension to give close regulation at light but varying loads.* Without them and with such tension the governor would race with standard or heavy loads.

The guide rollers G G are introduced in most high-speed engines to restrain the springs from bowing outward from centrifugal force. They are most needed when speed is 250 and upwards, and when the spring clips *d d* are short. [In one or two sizes clips of different lengths have been used.] The trouble that called for their use was due to the change in direction of pull on the clips in consequence of such bowing, and which caused racing when the amount of tension called for by calculation was applied.

Table of Governor Data

The governors are made in six sizes, numbered 1 to 6. The "diameter of wheel" will serve to identify any one the data of which may be wanted.

	Number of Governor	1	2	3	4	5	6
A	Diameter of Wheel (inches) . .	24	32	40	48	54	66
B	Spring leverage " . .	$4\frac{8}{16}$	$5\frac{1}{16}$	7	$8\frac{1}{2}$	$9\frac{1}{2}$	12
C	Weight leverage " . .	$8\frac{3}{4}$	11	14	17	19	24
D	Initial spring tension " . .	$2\frac{1}{2}$	3	$3\frac{7}{8}$	$4\frac{1}{4}$	$5\frac{1}{4}$	$6\frac{1}{4}$

DATA FOR WEIGHT CALCULATIONS

E	Effective wt. of levers (lbs. oz.)	$\frac{2}{12}$	$\frac{6}{12}$	$\frac{9}{12}$	18	20	32
F	Assumed wt. orbit (ft. diam.)	1	1.25	1.5	2	2	2.75
G	Resultant spring tension (in.)	3.25	4	5	6.25	6.5	8

Explanation of the Table

The diameter of wheel is given as before explained for identification. When making calculations or referring to data for any purpose, use only those under the given diameter which agrees with the wheel of the governor under consideration.

B. *The spring leverage is the distance* from the centers of the pivots of the levers to the centers of the eyes of the spring clips. It is adjustable, but the amount given is that on which all calculations are based. It is fixed at one-half of the weight leverage (*C*) for convenience of calculation. It is also very nearly all that can be had in each case, for reasons to be made clear presently, but it can be diminished in all cases.

C. *The weight leverage is the distance* from the centers of the pivots of the levers to the point where the whole effective weight of the levers and attached weights is assumed to be concentrated and which comes about central over the "lever stops."

D. *The initial spring tension, is, as nearly* as can be determined theoretically, the maximum tension that can be applied without racing, the "Spring leverage," (*B*) being as given and the auxiliary springs applied

and properly adjusted. It is more than could be carried in the absence of the auxiliaries, unless with very careful adjustment, and other conditions favorable. (See 71 and 129.)

E. *The effective weight of a lever is the* weight of an unweighted lever with spring clip in position to which is added one-half of the weight of a link (*B*, Fig. 12). The weight is found by resting the lever on the scales at the distance from the pivot given as the limit of

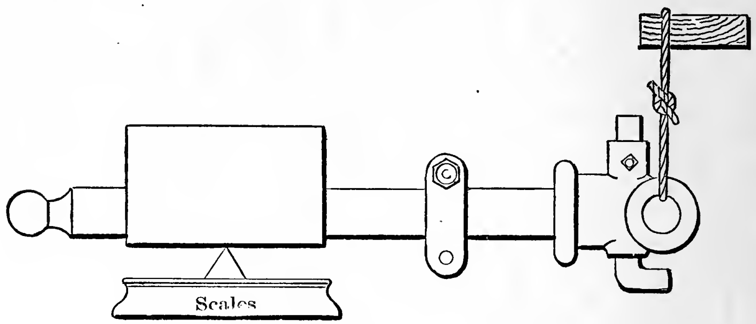

FIG. 13

the "weight" leverage (*C*) while the pivot is supported independently of the scales. (See Fig. 13.)

F. *The assumed diameter of the orbit of* the weights is an orbit somewhere within the range of movement of the levers, so chosen that its diameter will not contain inconvenient fractions of a foot, as it is assumed solely for purposes of calculation. The diameter assumed is immaterial provided the next item (*G*) is correctly deduced from it.

G. *The resultant spring tension is the* initial tension (*D*) augumented by the additional tension that would be imposed on the spring by moving the levers out-

ward till their centers of force reached the assumed orbit. (Neither this nor the initial tension can be given exactly for all cases, as the latter depends somewhat upon the position of the actual center of force, which varies in distance from the center of rotation, as the levers are heavily or lightly weighted, being farthest from the center with heaviest weights. But both weight and spring leverages are sufficiently adjustable to enable the desired speed to be attained when the calculated weight is attached.)

Use of the Table

To calculate the weight required for a given speed.

In addition to data furnished by the table, the force of the main springs in pounds per inch of tension will be needed. This will be generally found stamped on the cast heads of the springs; if not, the springs may be hung up and weighted till extended one, two or more inches, when the weight used divided by the inches extended will give the force, which for convenience may be represented by the symbol "f."

The first step in the calculation is to find the centrifugal force of each pound of weight revolving in the assumed orbit (F) at the given speed, which may be represented by "S." The desired force being represented by "cf" the formula will be, cf $= S^2 \times F \div 5870$.

Next we wish to find the spring force at the point of weight leverage (C) and in the assumed orbit (F) which we will represent by "sf." The weight leverage being twice the spring leverage the formula will be, $sf = f \times G \div 2$.

Then sf $\div$ cf = the theoretical total weight,* from which the item E is deducted, leaving the amount to be added to each lever.

Example. Find weights for No. 3 governor, speed (S) 180, spring force (f) 76 lbs. per in. The assumed orbit (F) 1.5 ft. and the resultant tension (G) 5 in.

For the benefit of those not familiar with formula we will give the rule arithmetically.

The force per lb. (cf) is found as follows: *Multiply the square of the desired number of revolutions per minute by the diameter of the orbit in feet* (F) *and divide by the constant number* 5870.

Thus $180^2 \times 1.5 \div 5870 = 8.28$ lbs. very nearly, that is, each pound in the given orbit will exert 8.28 lbs. centrifugal force.

Then the spring power 76 multiplied by the resultant tension (G, 5 in.) will give the total spring force at the *spring leverage,* the half of which will be the spring force at the *weight leverage.*

Thus $76 \times 5 \div 2 = 190$ lbs. Then $190 \div 8.25 = 22.94$ lbs. total weight required. Deducting one-sixth from this as per note below it becomes 19.12 lbs. or 19 lbs. 2 oz. Then 19 lbs. 2 oz. — 7 lbs. 14 oz. (E) = 11 lbs. 4 oz. to be added to each lever at point C.

For other speeds, other things equal, only the first

*Owing, however, to several disturbing influences, namely: — the centrifugal force of the spring itself; the friction of cut-off valve which acts in a direction to aid the spring, the inertia of valve and valve gear, the friction of yoke on eccentric and of eccentric on shaft, as well as friction of pivots, — a correction must be applied to this theoretical total weight. Experience shows that five-sixths of this amount is usually enough.

part of the calculation, finding the cf, needs to be gone over again.

Auxiliary Spring Adjustments

The function of these springs has been already explained.

They were first applied in the latter part of 1884, for the purpose of securing the exceptionally close regulation required for electric lighting.

As their adjustment cannot be perfected till after the engine is started, the shop adjustment (which is the best that can be made by a general rule) may in many cases require to be changed in order to secure the best results.

The test of perfect adjustment is, of course, *close regulation at all loads without racing at any load, and prompt response to changes of load without objectionable change of speed, momentary or permanent,* but by carefully observing the performance of the engine *at starting* the engineer can with a little experience tell almost as well when its adjustments are perfect and what changes may be needed, as by the test of regular running. But to do so he must first familiarize himself with the appearance of the governor sufficiently to be able to tell the moment the levers begin to expand as well as how quickly they do so, and to detect any irregularities in their outward movement.

Making white or bright colored spots on the weights with chalk, paint or paper will greatly assist such observations.

Perfect adjustment may be recognized by the following

performance: *On starting the engine gradually* the weights will not start outward till the proper speed is very nearly reached — so nearly so that the lack of it is not noticeable — when they will expand quickly but not violently, or so as to strike the outward stop; going out, however, nearly their full range, when if the load driven is heavy enough to require less expansion, they will promptly return to the requred position.

If, however, they make a few slight oscillations to and fro past their position no harm will result, if only they always settle in good time. *Very close regulation* requires that the *equilibrium shall be at the very verge of instability,* a proposition that will be recognized by all who have thoroughly studied the subject, *as true of all centrifugal governors.*

Auxiliaries too weak. The performance in such case will be the same in kind as though they were absent entirely, though more moderate in degree. On starting, the engine will run above its proper speed before the levers will expand, when they will fly out violently, and stable regulation will be possible only with loads so light as to regulate at one-fourth stroke cut-off or earlier, that is, such as require the levers to act only in the outer half of their range of movement. At heavier loads, the governor will race continually.

Auxiliaries too strong. On starting up the levers will start out at noticeably *less* than proper speed and expand gradually as speed increases till the limit of the follow of the auxiliaries is reached, when if they are much too strong, the expanding movement will stop a little till proper speed is reached, when they

will finish their expansion with proper promptness. The regulation will be the same as in both previous cases when the load is too light to bring the auxiliaries into action, but with heavier loads the speed will be slow in proportion to the undue strength of the springs. At maximum load, that is, just sufficient load to bring the levers to their inner stops, the speed will be reduced to about what was required to start them out.

In all of the three foregoing cases the tension of the main springs is assumed to be what it should be with the auxiliaries at their best adjustment.

To enable the engineer, whose engine is without them, to judge whether and to what extent his regulation would be improved by their application, we give a description of a performance capable of improvement, assuming the tension of the main springs to be all that can be carried without racing at any load, which *is always less than will be needed when auxiliaries are applied.*

Best regulation without auxiliaries. At starting the levers will not start out till proper speed is nearly reached (as per 81), but they will expand quickly *only in part;* from about mid-movement outwards the expansion will go on only as speed increases, requiring a greater increase of speed to expand them to near their outer limits than that which sufficed to expand them through the inner half of their movements.

The regulation in such case may be good at all loads requiring one-fourth stroke cut-off and later but with lighter loads, requiring earlier than one-fourth stroke

cut-off, the speed will vary much more with a given change of load than with heavy loads.

The strength of the main springs is however a factor of some influence in determining the degree to which the foregoing performance falls short of perfect regulation. The stronger they are the closer the regulation, throughout the whole range, that can be had without the help of auxiliaries.

From the above it might appear that, given main springs strong enough, the auxiliaries might be dispensed with entirely, which is true in some cases; yet the strength necessary to obtain that result in all cases would impose such severe pressure on the lever pivots that the resultant friction would interfere to some extent with fine regulation.

It is a matter of many year's experience that the closest and most sensitive regulation possible requires that the forces in equilibrium within the governor be not so great but that the work imposed on it will very slightly disturb the equilibrium at each stroke, so as to *overcome the static friction of the joints and eccentric sleeve*, and enable the parts to adjust themselves to the load requirements without having to await an objectionable change of speed to do it. And when the forces are weak enough to be thus sensitized there is left a small margin of improvement to be effected by the auxiliary springs.

Applying auxiliary springs to old engines. As before stated they were not used till 1884, and although many have been since applied to engines built before that time, there are still many running without them.

The indications for their use have been already given, but when such indications are present, the main springs should be examined, and if of the kind now made, namely, with hooks on one end only, the other being closed with a cast head threaded for the tension screw, and if figures can be found stamped on the heads we would recommend the parties to advise us as to the power of their springs, and if the requirements for regulation are not exceptionally exacting, it may happen that a stronger pair of springs, with required weights, will be better on the whole than the application of the auxiliaries. (Our records, however, give the spring force in all engines shipped since and including October 9, 1882.)

To apply auxiliary springs. This should be done in all cases where *best possible* regulation is desired, as is generally the case with electric lighting plants or engines to be used wholly or partly for that purpose.

We can send the springs, bolts and fingers adapted for use with existing levers, as shown in Fig. 14, or we can at not materially greater cost send new levers with fingers fitted as shown in Figs. 12 and 13.

To fit to existing levers, $\frac{5}{8}$-in. or $\frac{11}{16}$-in. holes should be drilled through the cast heads of the levers as near the pivot holes as possible without danger of breaking into them, and at right angles to both the levers and the pivot holes. The surfaces around the holes at each side should be faced by chipping, or better, "*rousting*" if a machine-shop is in reach, — to receive the lock-nuts shown, and give them a fair bearing.

The springs are bolted to the rim as shown in Fig. 12, the angular position selected being such that the fingers will just catch with certainty at their *shortest reach.*

When the springs are secured in position, the eccentric should be turned forward till the fingers leave

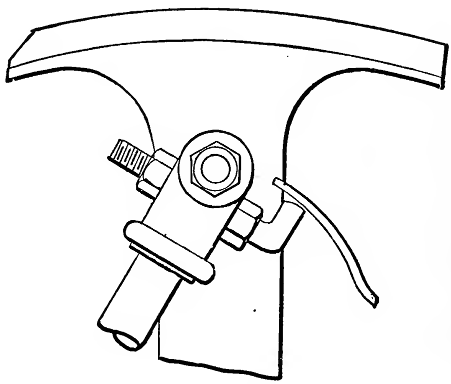

FIG. 14

contact with the spring, which should happen when the levers are about half way out or a little more. If they leave contact too early or too late, they should be taken off and bent outwards or inwards, as required, till they follow as above. They are not tempered and will not break.

Add tension to the main springs till regulation is as close as desired between lightest and medium or standard load.

Correct the speed by adding to weights, shifting them from pivots, or diminishing spring leverage, or by two or more of these adjustments.

Compare performance with foregoing descriptions. If

the springs appear too weak give the fingers more reach. If too strong (as will be more likely the case) take one of them off. If still too strong, grind one weaker and use it alone. Grind liberally and fearlessly, for if it is made too weak the other can be similarly ground and applied, or finger given more reach. *Strength is easier got than weakness,* yet the lesson is more instructive if the point of insufficient strength is reached and carefully corrected.

To Change Speed

For any considerable change of speed the weights should be changed, the proper weight for desired speed being found by rules already given.

Slight changes, however, can mostly be made by adjustments, of which the following are preferable:

To Increase Speed

A. *Increase of spring tension may be tried,* and if when the desired increase of speed is effected in that way the regulation remains sufficiently stable, *i.e.,* free from tendency to race at any time, the correct adjustment has been made, and the regulation will be closer than before. But if the tension has been made what it should be — all that can be carried without racing — it cannot be increased, in which case

B. *The weights may be shifted* towards the pivots of the levers, provided they are not already as far in that direction as permissible. [They should not be far from central over their stops in that direction.]

C. *The spring leverage may be increased* by slipping the spring clips farther from the pivots, provided the link heads are not thereby caused to strike the springs at mid-movement, as may be tested by turning the eccentric forward past its mid-position. A slight interference so detected will not matter, as when running, centrifugal force will bow the springs outward, if not too closely restrained by the restraining rollers now applied in many cases to high-speed engines.

When the spring leverage is increased, an increase of spring tension equal in amount to about one-half the increase of leverage becomes admissible as *the maximum possible tension is a certain portion of the leverage* (not to the same in all cases exactly, however), not a certain absolute amount.

To Decrease Speed

From the foregoing it will be evident that

A. *Spring tension may be reduced* if leverage is reduced twice as much at same time, without introducing greater speed variation, as *reducing spring tension alone would do.* But this adjustment should not be resorted to for any considerable change of speed, as it introduces objectionable weakness in the governor.

B. *The weights may be shifted* farther from the lever pivots, if not already so far from their normal position in that direction as to render any further shifting objectionable, though no trouble is to be apprehended so long as they are clear of the links in all positions.

C. *Spring leverage may be reduced* without con-

current *reduction of spring tension,* provided the latter is not at a maximum. The test of that is the *performance;* if *racing* is not induced, the adjustment is admissible.

To Reduce Speed Variation

A. *Increase spring tension,* if possible without danger of overstraining.

B. *Diminish spring leverage,* if not already as much as advisable less than normal.

C. As A increases speed and B reduces it, a certain combination of both together, that is, about twice as much reduction of leverage as increase of tension will accomplish the desired result without change of mean speed.

If racing results, note whether it occurs at heavy loads only, or at all loads. If at heavy loads only, *make the auxiliary springs follow noticeably more than half of the lever movement,* and try first with one of them removed, and if one alone appears too weak, try greater reach of finger.

If all adjustments of the auxiliaries, however, fail to cure the racing, it may be concluded that the previous adjustments A B have been overdone.

Racing from All Causes

Enough has been said to make the engineer perfectly familiar with the fact that racing may *always* be stopped by reducing spring tension, increasing spring leverage, or both, and nearly always by increasing the

force, or prolonging the follow of the auxiliary springs. But cases may arise when none of these adjustments should be made. Such is presumably the case when it appears spontaneously under adjustments that have previously given satisfactory regulation, and also when the tension is not in excess of that given in the table, and it refuses to yield to any moderate auxiliary spring force or follow, and particularly if, when cured by auxiliary spring adjustments, the speed variation with load changes is objectionably great.

In such cases *undue friction* will undoubtedly be found to be the cause of the trouble. It may be in the lever pivots, the ball and socket joints of the links or the loose eccentric on the shaft, one or more of these bearings; and may be caused by over tightness, lack of oil, rust or gum. Only the ball joints can be tested without taking the governor apart, the play at the necks of the balls, allowing the links to be slightly rotated back and forth, and when this can be done easily they are free enough. The lever pivots can be tested by taking off the retaining nuts and washers of the studs and slipping the levers partly off, when the condition of the exposed surface will be apparent, and the needed remedy (cleaning and oil) readily applied. But to test the condition of the eccentric bearing perfectly, the eccentric should be both unstrapped and disconnected from the levers so as to be rotated freely on the shaft. If dry or gummed, it may be simply oiled with or without preliminary doses of turpentine or kerosene, but if this fails to eliminate all sticking points, the governor should be slipped back or taken

off to allow the eccentric to be moved aside (the larger sizes are made in halves and hence can be removed) when any brusies or tight points can be discovered and corrected.

New engines will seldom require such treatment unless the eccentric has been too closely fitted, but older ones, especially after standing some time, or the use of gummy oil, may need it.

The kind of racing caused by friction is, however, noticeably different from that due to over tension or insufficient auxiliary spring force, as follows: when caused by friction the levers will expand and *stick* in that position till speed falls more or less according to the amount of friction, when they will drop in and again stick till the speed increases sufficiently to again expand them, and so on. Apparent sticking on the *inner* position is not to be taken as evidence of friction, since that will happen with insufficient auxiliary spring force; but nothing but friction will cause *dwell* in the outer position, during considerable change of speed.

Over-packing the cut-off stem will disturb the equilibrium of the governor and cause irregular action, but not usually racing as above described, but rather irregular flopping in and out of the levers.

The cut-off stem should not be packed with any of the hard kinds of packing, and such soft kind as may be used (candle wick is as good as anything) should be renewed often enough to avoid the necessity of screwing it up so tight as to cause friction enough to disturb the governor and wear the rod out.

Undue friction of the eccentric straps, whether from

lack of oil or too light adjustment will sometimes cause racing, accompanied by *acceleration of speed,* much as though the spring tension had been considerably increased. Some acceleration of speed always results from this cause, even when racing does not, and the same is true, though to a less extent of undue friction of the cut-off valve, its stem packing or its rocker-shaft and pins; and, as no other accidental change (except the slipping backwards of the governor wheel) can cause acceleration, when that symptom appears attention should be at once directed to the conditions of the parts named.

The difference between the effects of undue friction of the above-named parts, and of the working parts of the governor and the eccentric on the shaft should be well understood by the engineer. Friction of the latter parts may be called *static* friction, as it tends to hold the parts concerned *stationary,* relatively to the shaft and wheel, as against the movements required for cut-off variation, *in both directions alike,* while friction of the other parts named tends to pull the levers of the governor *inwards,* hence it may be called *dynamic* friction, or since inward pull on the levers is a *centripetal* action, like that of the main springs it may be more descriptively called *centripetal* friction.

From the above it will be understood that it is the *static* friction that most tends to cause racing when in excess. Of the parts concerned in producing *centripetal* friction only undue friction of the eccentric straps will cause racing, because that of the other parts,

being absent at the dead centers of the eccentric movement, is too intermittent to cause any other disturbance than that already described in Sec. 116. The eccentric strap friction, on the other hand, is tolerably constant, and consequently acts like increased spring tension.

It will be seen from the foregoing that there are *three* frictional effects going on in the governor, namely, the *static*, the *constant centripetal*, that of the eccentric straps only, and the *intermittent centripetal*, that of the cut-off valve, its stem and the joints and bearings of its gear.

The *static* and the *intermittent centripetal* frictions, when normal, counteract each other's bad effects, so that regulation can be, and mostly is, *as sensitive as though all parts were entirely frictionless*. Thus, the former prevents the latter from jerking the levers inward to an objectionable degree each stroke, yet not so effectually but that it (the static friction) is overcome and the eccentric turned by a minute amount at each jerk, while it recovers its position by contrary movements between jerks. The static friction being thus overcome four times in each revolution, in each direction alternately, is *practically neutralized* leaving the governor entirely free to respond instantly to all changes of load or pressure.

The *Constant Centripetal* effect of the friction of the eccentric straps has no material effect on the *sensitiveness* of the governor; it only slightly increases speed, other things equal.

But this centripetal effect is not uniform through-

out the range of movement. It is the greatest at the extremes of the range where the angle formed by the links B B (Fig. 12) with a line joining the pins in the eccentric ears is acute or obtuse, and least near the middle of the range where it is a right angle. From this fact results the need for the auxiliary springs. The entire theory of the matter need not be explained here; — the leading lacts being sufficient for those who do not care to study the subject exhaustively.

The auxiliaries permit the spring tension to be adjusted to the requirements of the outer half of the range of movement, while they prevent the tension from being in excess during the inner half, as it would otherwise be.

The Theory of Spring Tension

The force of a spring increases in direct proportion as it is bent (by extension in present case, or in whatever way it is acted on), and the centrifugal force of a body in like manner increases in direct proportion as it moves farther from the center of motion, the number of revolutions per minute remaining constant.

Consequently, in the absence of all disturbing causes, if in a governor of the kind in question, the spring tension be made such that if the lever be moved inwards till its center of force reaches the center of motion, or a line joining its pivot and the center of motion, in other words, its *zero of centrifugal force,* it (the spring tension) would reach its zero at the same time, the two forces would increase in the same ratio (at a constant rotative speed) as the lever moved

outward, and consequently the speed would be the same at all points in the range of movement; in other words, the regulation would be *isochronous.*

But suppose the tension to be less than this, so that as the lever moved inwards the zero of spring force would be reached before that of centrifugal force, then, as it moved outward the spring force would increase more rapidly than the centrifugal force at a constant rotative speed, so that a constantly increasing speed would be required to keep the forces in equilibrium, and the number of revolutions the speed would have to increase in order to carry the lever outwards through its range of movement would be the extreme measure of the governor's variation. Thus, if 100 revolutions in a given time be required to start the levers outward, and 105 in same time to expand them to the outer limits of their range, the extreme variation would be 5 per cent., which would be tolerably close regulation, seeing that in practice the changes of load and pressure seldom cover more than half the range.

To Obtain Closest Possible Regulation

Although enough has been said in Secs. 80 to 100 to cover the entire ground, yet a concise rule in this place will be convenient.

1st. Give the main springs all the tension that can be carried without racing at any load from nothing up to near quarter cut-off, as nearly as can be judged. If indicator cards can be taken to show range of cut-off the test will be far more intelligible. If tension

cannot be given as desired, on account of fear of over-straining the springs or lack of room at the tension screws, the spring leverage may be reduced a little; but in some way get tension or its equivalent, till the regulation within the above range is as close as desired.

2d. Count the speed at as heavy a load as can be applied with certainty that the weights do not touch their stops. If indicator cards can be consulted, apply load till it shows about half-stroke cut-off. Generally, as the auxiliaries are adjusted at the works this speed will be too slow. If it is more than 3 or 4 per cent. slower than the light load speed, reduce the auxiliary spring force till the speed is brought up as near the light load speed as desirable. Reduce first by diminishing the finger* reach as much as possible, and if this fails to bring the speed up as desired, take off one of the springs. If still too slow, grind the remaining one weaker unless it is found that it follows three-fourths of the distance out or more, when it may be sprung together a little, but in no case so much as to reduce the follow to one-half the movement. It should be noticeably more than half, unless less is finally found to be better by actual comparative test. If now no racing occurs at any load, the adjustment will probably be as perfect as desired, though a count of as many intermediate loads within the range of the action of the auxiliaries as possible may reveal some irregularities worth while correcting. For instance, if on counting under a series of loads from

* The "fingers" are shown in Fig. 12, at *p. p.* Reference to them in proper place was inadvertently omitted.

heaviest down, the gain of speed as load diminishes is found to be proportionately too rapid at first, the auxiliaries should be made to follow out farther, but at the same time weakened sufficiently to prevent making the half-cut speed any slower, as would happen if the spring or springs were simply opened to prolong the follow.

But the last correction is unnecessary if no signs of racing appear; the regulation within the proper working range will be closer without it, but bear in mind that with too short follow the light load regulation may be perfect and the half-cut speed not objectionably slow, yet at certain loads between half and quarter-cut it will race, or come too near it for perfectly satisfactory performance.

To Change the Direction of Motion

The main eccentric follows the crank about 60 deg.

The governor, however, must be taken apart entirely; the lever pivot studs *b b* removed to the holes shown as used to attach the guide roller carriers *G G*, but which will be found unused when guide-rollers are not applied; the tension screws *c c* placed in the extra holes that will be found in the proper place; the auxiliary springs similarly removed to the places provided for them, and the whole put together as shown in Fig. 12, if that view shows the desired direction of motion, as shown by the arrow, or as it would show if viewed in a looking-glass, if it represents the reverse of the desired direction.

The simple rule, to so put together that when the engine runs in the desired direction the pivoted ends of the levers will *lead,* the *weights follow,* and so that when the levers move outward the eccentric will be *advanced, i.e.,* turned on the shaft in the direction the engine is to run, will cover the case so far as instructions should be needed, the proper application of the main springs auxiliaries and guide-rollers (if any) being simply a matter of making them perform their functions as before.

The new angular position of the wheel is found by the fact that when the weight levers are on their inner stops, the governor eccentric and crank will be on their dead centers at the same time and in the same direction.

V

STRAIGHT-LINE ENGINE GOVERNOR

THIS governor, a cut of which is shown in Fig. 15, is the design of Prof. John E. Sweet. It comes under the second class of the second group described in Chapter I.

The eccentric *A* is mounted on the disk *B* and is pivoted at *C*. The eccentric center swings across the shaft center when actuated by the weight *D*. This weight is pocketed for shot to admit of changes by taking away or adding to the weight. The weight and arm are in one piece, pivoted by the pin *E*. The end of the weight-arm is connected to the eccentric disk by the link *F*. The spring *G* is made fast to the weight-arm by the band *H*. The adjustment of the spring-tension is obtained at the point *J* by slacking or screwing up the binding bolt *K*.

To increase the speed of the engine, increase the tension of the spring, or decrease the weight, or both.

To decrease the engine-speed, decrease the spring-tension, or increase the weight, or both.

Bear in mind that if the proper sensitiveness has been reached and only the speed is to be changed, the change should be made in the weight alone.

If the governor is sluggish, first see that everything

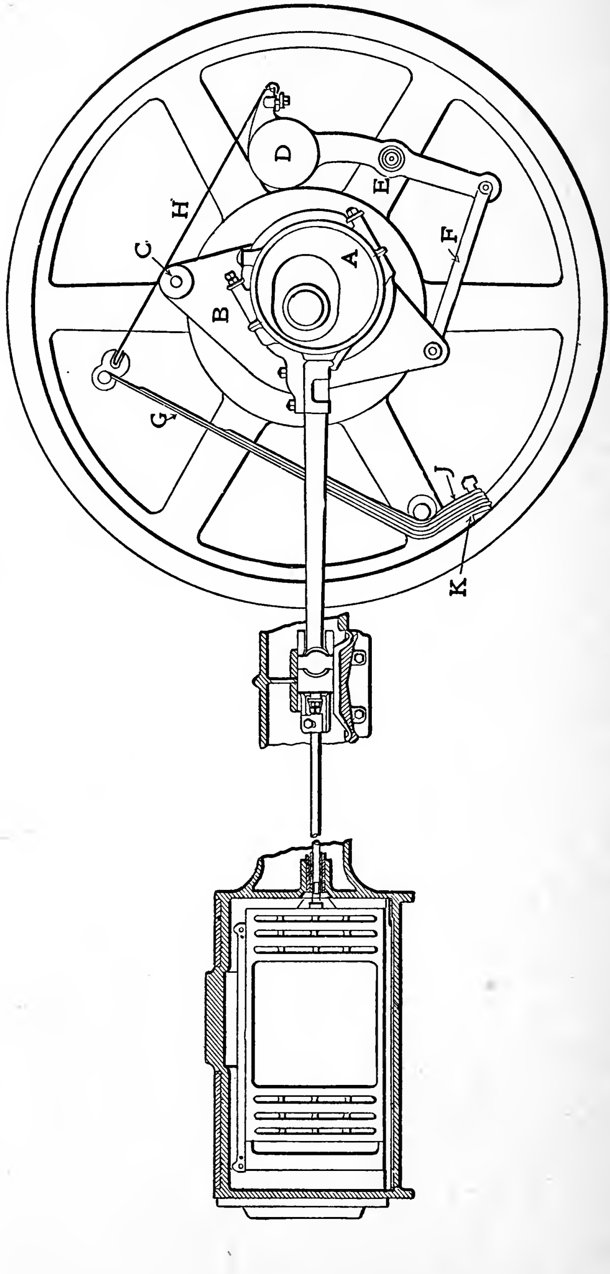

FIG. 15

relating to the valve-motion is free; then, if still sluggish, add more spring-tension and more shot in the weight pocket.

If the governor races, it may be due to sticking in some of the joints or in the valve-rod; if these are free, decrease the spring-tension and take away shot from the weight.

VI

IDEAL ENGINE GOVERNORS

The A. L. Ide and Sons Co. use the Rites Inertia Governor on the engines they now put out, and have done so for some time past. Chapter III of this book, with the remarks here given, covers all there is to be said in reference to the adjustment of these governors.

The Ide Company has made an improvement in the Rites governor in the shape of a revolvable bronze bushing shown at *A* (Fig. 16). Owing to the fact that great wear comes on this pin, this bushing is placed there, so that a new surface can be turned to the wearing side of the pin frequently. This is done with a spanner-wrench which comes with the engine. The builders recommend that the bushing be revolved a little each day when the governor is oiled. On the face of the lug *B*, on the pulley-spoke to which the spring is attached are stamped figures which indicate, first, the speed of the engine, and second, the distance that the eye-bolt should extend through the nuts in order to adjust the governor as it was adjusted when the engine was tested in the shop. The spring is attached to the governor-bar by means of a sliding block *C* (Fig. 16). The block is in

the correct position when the line marked on it is even with the line marked on the bar.

These builders, in former years, put on the market a centrifugal governor of which Fig. 17 is a cut, and

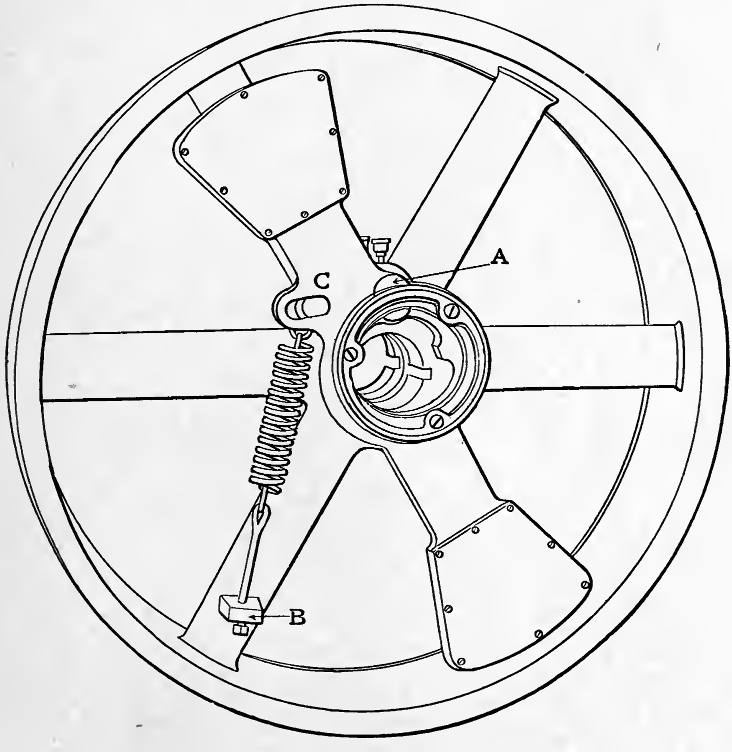

FIG. 16

as many are still in use, some instructions regarding them will follow. In taking this governor apart for oiling and cleaning, allow the sliding block *A*, which holds the end of the governor-spring, to remain with its outer edge on a line with the mark across the face of the slide, and in readjusting the spring, place the

same tension on it as was on it originally. This can be ascertained by measuring the length of thread through the nuts before slackening them. On this type of governor which is designated in the second

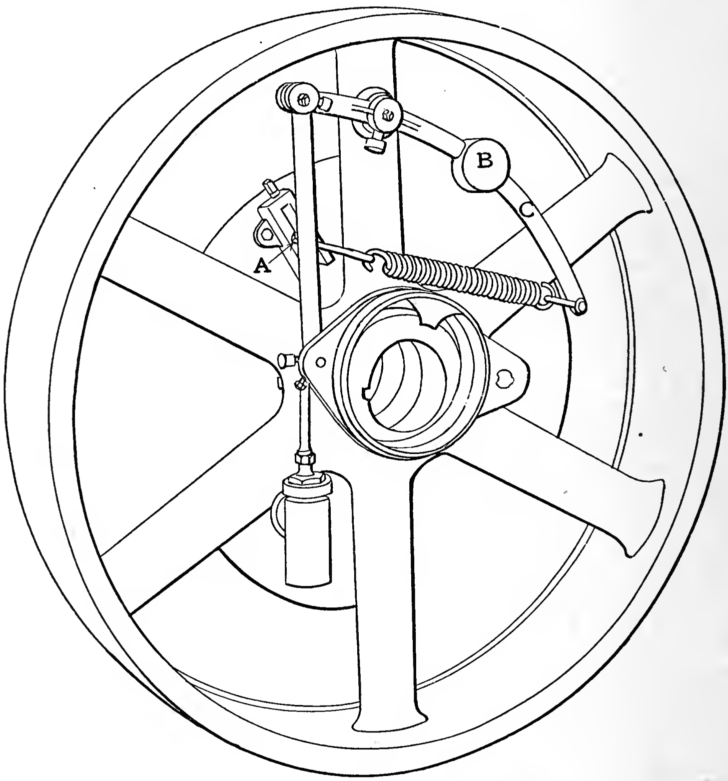

FIG. 17

class of the second group in Chapter I, the weight *B* can be moved back and forth on the lever *C* by slackening the set-screw until the weight can be moved by hand. This will have the effect of adding to or taking from the weight.

Moving the weight out toward the end of the lever has the effect of increasing it, and *moving it in* toward the fulcrum pin *D* has the effect of decreasing the same.

Changes of speed should be made with the weight.

To get increased speed move the weight in toward the fulcrum-pin.

To decrease speed, move the weight toward the end of the lever.

To make the governor more sensitive, move the block A, Fig. 17, toward rim of wheel.

To make it less sensitive and correct it for racing, move block A toward hub of wheel.

The face of the slide is marked with a line where the outer edge of the block which holds the spring should stand. Figures stamped on the face of the slide show the distance that the end of the eye-bolt should extend through nuts. This gives the right tension on the spring. Tightening the spring will give closer regulation, but if the spring is too tight, it will cause the governor to "race." "Racing" caused by over-tension of the spring can be stopped by moving the block nearer to the center of the wheel.

VII

ADJUSTMENT OF FLEMING ENGINE GOVERNORS*

THE governor used on Fleming engines, built by the Harrisburg Foundry and Machine Works of Harrisburg, Pa., is of the "Centrally Balanced Centrifugal Inertia type," shown in Fig. 18. Assuming one of these governors to be out of adjustment, the weights being removed from pockets *A* and *B* and the springs loose, in order to properly adjust proceed as follows:

FIRST ADJUSTMENT

Locate the outer ends of the springs about the center of the slots, refer to table (page 76) for the size of spring corresponding to that in the governor, noting the initial deflection. Draw up the two bolts *C*, *C*, sufficiently to stretch each of these springs by the amount of this deflection. Now start the engine and bring it up to speed, pocket-weights being removed and springs given tension shown in the same table. If the engine runs much too slowly the springs are too light and a heavier set should be used to get the desired speed. If, on the other hand, it runs too fast, add one

* This governor comes under the second class of group two in Chapter I.

weight of equal thickness to each of the pockets, *A* and *B*, placing the weights of larger diameter in *A*

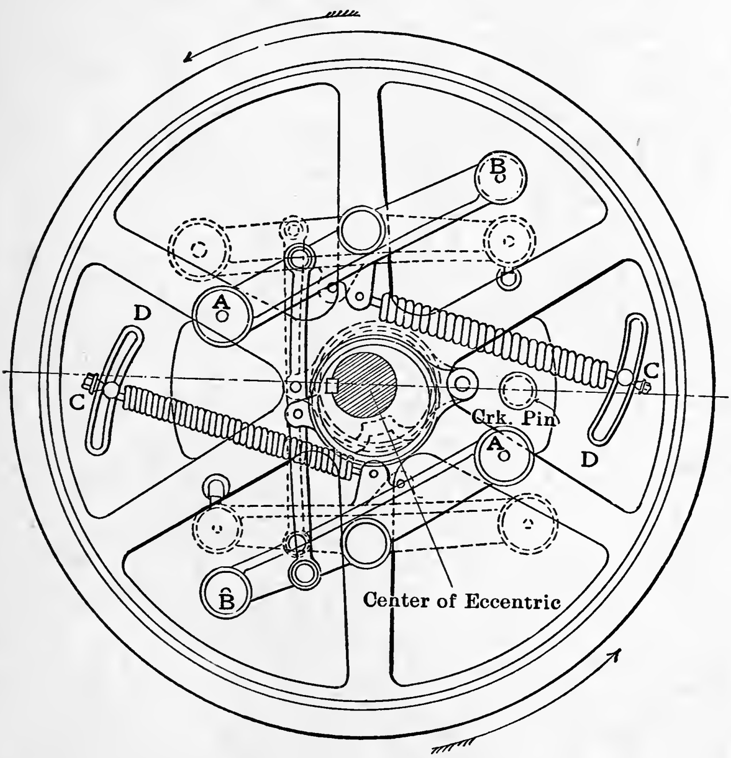

FIG. 18

pockets and the smaller ones in *B* pockets; if it still runs too fast, add another set of weights of equal thickness, selecting the proper thickness to reach the desired speed.

SPRINGS FOR HARRISBURG GOVERNORS

O. D.	Wire	Total Coils	Init. Def.	Def. Due to Gov. Throw	Total Extension
2."	$\frac{5}{16}$"	23	1 $\frac{1}{2}$"	1$\frac{1}{8}$"	2 $\frac{5}{8}$"
1$\frac{3}{4}$"	$\frac{5}{16}$"	27	1$\frac{9}{16}$"	1$\frac{1}{8}$"	2$\frac{11}{16}$"
2 "	$\frac{3}{8}$"	33	1 $\frac{3}{8}$"	1$\frac{1}{2}$"	2 $\frac{7}{8}$"
2$\frac{1}{8}$"	$\frac{3}{8}$"	33	1$\frac{5}{16}$"	1$\frac{1}{2}$"	2$\frac{13}{16}$"
2$\frac{1}{4}$"	$\frac{3}{8}$"	33	1 $\frac{1}{2}$"	1$\frac{1}{2}$"	3 "
2$\frac{1}{4}$"	$\frac{7}{16}$"	33	1$\frac{9}{16}$"	1$\frac{7}{8}$"	3$\frac{7}{16}$"
2$\frac{3}{8}$"	$\frac{7}{16}$"	35	1 $\frac{1}{4}$"	1$\frac{7}{8}$"	3 $\frac{1}{8}$"
2$\frac{1}{4}$"	$\frac{7}{16}$"	39	2 "	2$\frac{1}{4}$"	4 $\frac{1}{4}$"
2$\frac{1}{2}$"	$\frac{1}{2}$"	39	1 $\frac{3}{4}$"	2$\frac{3}{4}$"	4 $\frac{1}{2}$"
2$\frac{3}{4}$"	$\frac{9}{16}$"	39	2 $\frac{3}{8}$"	2$\frac{1}{2}$"	4 $\frac{7}{8}$"
3$\frac{1}{4}$"	$\frac{5}{8}$"	31	3 $\frac{1}{2}$"	2$\frac{3}{4}$"	6 $\frac{1}{4}$"
3$\frac{1}{2}$"	$\frac{5}{8}$"	33	3 "	2$\frac{3}{4}$"	5 $\frac{3}{4}$"

TO ADJUST TO THE PROPER POINT OF SENSITIVENESS

If the governor "races" or "weaves," move the clamp to which the outer end of the spring is attached in the slot farther from the rim of the wheel, that is, toward *D*. If this does not entirely correct the racing tendency, screw the spring-plugs farther into the springs and adjust the tension for proper speed. Taking out thin weights of equal thickness from each pocket and reducing the spring tension also assists in checking a racing tendency.

TO CORRECT SLUGGISHNESS

If the governor is too sluggish, that is, not sufficiently sensitive in order to reach the proper speed,

add a thin weight of equal thickness to each pocket and increase the spring-tension. The spring-tension, however, must not be increased to such an extent as will make the initial deflection, when added to the deflection or tension due to governor throw, greatly exceed the total deflection shown in the last column of table, and corresponding to that of these springs. While the total extension of the springs may sometimes slightly exceed that given in the table, there is danger of injury to the spring by a greater extension. If still greater sensitiveness is desired, move the clamp to which the outer end of the spring is attached, in the slot nearer to the rim of the wheel. Screwing the plugs a part of a turn out of the springs and increasing the tension will make the governor more sensitive.

If, with these adjustments, the governor cannot be made sufficiently sensitive, the springs are too heavy, and a lighter set should be used.

In cases where these governors are equipped with dash-pots, a sluggish action of the governor on starting up in a cold engine-room is sometimes due to the fluid in the dash-pot being cold and thick. This trouble will usually disappear after the engine has run a short time.

To Correct for Speeding Up

If the engine speeds up when the load is thrown off, it is either because the valve has too much lead or is sticking through lack of proper lubrication, or may possibly be leaking, due to wear, as speeding

up, due to the adjustment of these governors, is not likely to occur.

Care of Governor

The governor is a simple piece of mechanism, but it is one of the most important parts about the engine,

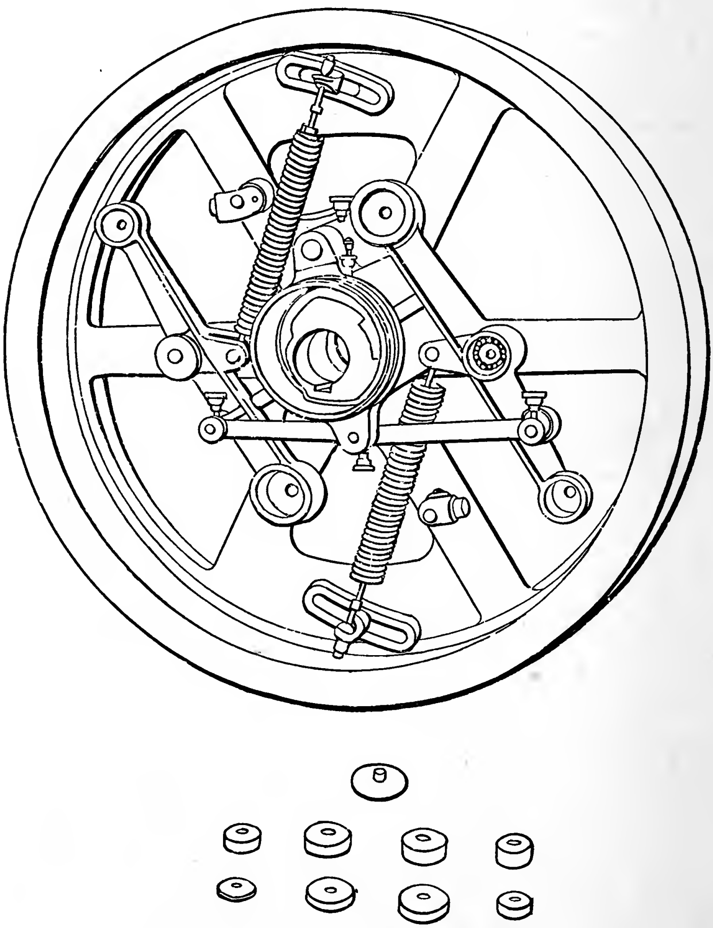

FIG. 19

and should be so treated. The springs should be disconnected occasionally, and the governor parts and valve gearing should be tested, by hand, for freedom of all bearings and joints. It is also a good plan to take the governor bearings apart occasionally, and examine them to see that they are getting proper lubrication. Clean them thoroughly before putting them together again. Before starting up the engine always see that all bolts and nuts are tight. If the governor is equipped with dash-pots keep them full of either glycerine or equal parts of cylinder and engine oil. Fig. 19 shows the governor with the weights out of the pockets.

VIII

McINTOSH, SEYMOUR AND CO.'S ENGINE GOVERNOR

This type of governor comes under first class and group of Chapter I. The governor is shown in detail

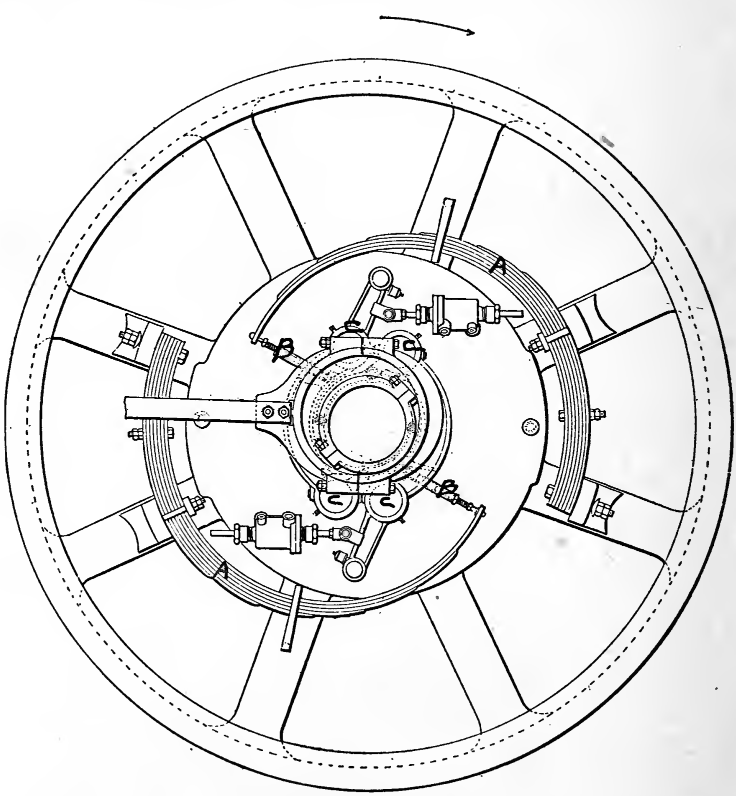

FIG. 20

in Fig. 20. This figure shows the one governor in two positions.

The position of the governor parts when the engine is not running is shown at the left. The centrifugal

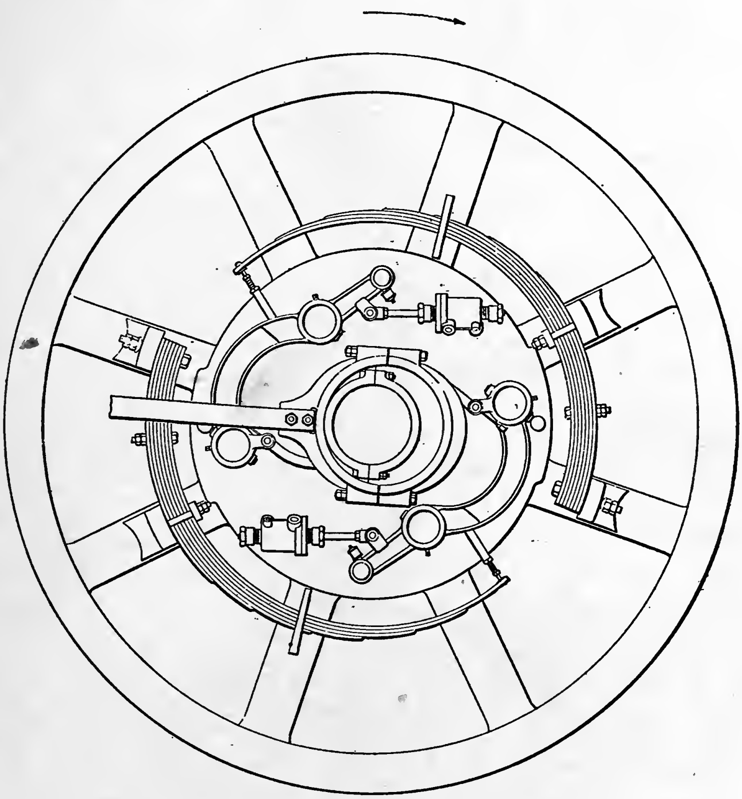

FIG. 20

weights are at their inner limit of travel and the governor eccentric is so placed as to give maximum cut-off. In the view at the right the centrifugal weights have moved into their extreme outer position, and at the same time have pulled ahead the eccentric, to

which they are connected by links and which is free to revolve on the shaft, sufficiently to cut off the steam entirely from entering the cylinder. This condition is approached when the engine is running and the load is thrown off. The centrifugal force of each weight is opposed in a direct and practically frictionless manner by a plate-spring *A, A*, through a hardened steel pin *B, B*, with a ball-and-socket bearing at the end of the spring and at the center of gravity of the weight, so that there is no friction or pressure due to this force upon the pin upon which the weight swings. This permits the use of a very heavy weight, having great centrifugal force and making the governor powerful. There are provisions for grease lubrication of all wearing surfaces. The tension pins between springs and centrifugal weights are arranged to telescope, in order that they can be adjusted to secure proper sensitiveness; for by lengthening these pins the governor can be made to regulate more closely, and by shortening them, over-sensitiveness or racing can be removed. Dash-pots are provided, which give stability to the governor, so that it can be adjusted to give nearly perfect regulation without any tendency to race under a fluctuating load.

The speed at which the engine will run can be raised or lowered by reducing or increasing respectively the small lead weights *C, C, C, C*, provided for that purpose in holes in the centrifugal weights. This adjustment should be made last, for it does not alter the sensitiveness of the governor to change the speed in this way,

while any adjustment of the sensitiveness as described above also changes the speed.

The governors of McIntosh and Seymour engines, when designed for driving alternating-current generators in parallel, are provided with patent compound time-delayed dash-pots, without which successful parallel operation is impossible with generators of large size and high frequency. When two alternating-current generators are running in parallel, each generator has a tendency to oscillate back and forth with reference to the other, with periodic transfer of load from one generator to the other, called "surging." A governor, which is properly sensitive, without the time-delay dash-pot, must respond to these fluctuations of speed, and when the conditions are such as exist with large generators of high frequency, resonance is produced; that is, the action of the governor tends to increase the speed fluctuations, causing the surging to build up from an imperceptible beginning until parallel running is impossible. If the governor is dampened by ordinary devices sufficiently to stop this effect, it will fail to control the speed properly, with danger of the engine running away if a considerable part of the load is suddenly thrown off. The compound time-delay dash-pots dampen heavily the governor-action for any fluctuations of speed of very short duration, such as those just described; but under the action of even the slightest change of speed, if persistent beyond this short interval of time, they automatically release the governor avoiding any impairment whatever of the speed regulation.

A speed changer is sometimes placed on governors where synchronizing of units is desired.

The mechanism of the speed changer consists of an auxiliary weight arranged to slide on the main centrifugal governor-weight, while the engine is running, in such a way as to change the speed of the engine by altering the centrifugal force to be resisted by the governor spring. The auxiliary weight is moved by a screw which in turn is rotated by a small electric motor mounted on the governor-weight.

This motor can be connected electrically, through a collector on the engine shaft, to a double-throw starting-switch on the station switchboard, in such a manner that the amount and direction of the motion of the electric motor can be controlled by the starting-switch so as to give the desired change of speed.

Adjusting Governor of a New Engine

Put all the lead pieces in the holes in governor-weights and tighten the set-screws well down into them. Then, with the shortest length of tube in the governor adjusting pins (*B*, *B*, Fig. 20), put the pins in place between ends of springs and governor-weights, care being taken to have the ends of pins well greased. Be sure that the bolting of governor-spring is secure, and that all governor parts are ready for service. Then start the engine non-condensing and without load, opening the throttle little by little so that the speed may increase very gradually.

Count the speed from time to time to make sure

that it does not exceed the rated or normal speed by more than 5 per cent. At no time should the speed be allowed to exceed this amount. If the above instructions have been followed the governor will probably control the engine at some speed considerably below its normal speed. If, however, the engine runs up above normal speed, and the governor-weights have not then opened wide, the governor does not control the speed properly and it may be necessary to change its adjustment. Before doing this, however, make an examination as follows: See that the springs do not rub hard against the spring-guides, and that they do not strike the bottom of spring-guide or any other part of the wheel when in outer position. Then remove the springs, disconnecting the auxiliary eccentrics from the valve-gear, and see that the governor-weight when connected to eccentric-sleeve, swings freely from inner to outer positions and strikes against stop-pins. Make perfectly sure that eccentric-sleeve turns freely on shaft. Connect up valve-gear again and make sure while turning the engine a complete revolution, that the cut-off valves are entirely closed when the governor-weights are in the outer position.

If no trouble has been discovered in any of these particulars remove the second leaf from each spring, considering the shortest leaf as the first. Then start the engine and run up to speed as before. If the weights do not open, remove the fourth leaf, and, if necessary, the fifth and sixth.

The object of the foregoing operations is to secure

governor-control of the engine at some speed below the normal, and at the same time obtain a sluggish regulation. The next step should be to secure correct adjustment of the sensitiveness of governor, to give proper closeness of regulation, after which the speed should be adjusted to the desired number of revolutions per minute.

When the governor-control has been secured as above, the sensitiveness of governor will probably be found to need increasing by increasing the length of the adjusting-pins between the governor-weights and the ends of the governor-springs. The adjusting-pins should be gradually lengthened one-half inch at a time, until the proper sensitiveness is reached, always keeping the length of the pins the same. These adjusting-pins should have been unscrewed before putting them in position, and the length of the threaded parts measured, as, when in position, at least 1¼ inches of threaded part must always be left in the socket. If longer pins are required than this will allow, put in the next longer set of the tubular parts of the adjusting-pins.

At the start the sensitiveness of the governor should be made such that when the load is removed the increase of speeed will be not less than 3 per cent. After the engine has run awhile the sensitiveness can be increased sufficiently to make the corresponding increase 2 per cent. In determining the speed of an engine always count the speed for several consecutive minutes, and divide the total number of revolutions by the number of minutes during which the speed is

counted. The speed-light should always be taken after the load has been removed.

In many cases it is not convenient to secure a load for testing the sensitiveness of governor, as has been just described, when an engine is first started, and generally the easiest way of securing a proper preliminary adjustment of sensitiveness, with engines of small size, is to continue lengthening the adjusting-pins until the engine "races." Then reduce the length of pins until "racing" ceases. With large engines it is frequently impossible to make them race. In such cases an approximate preliminary adjustment of sensitiveness may be made, when not convenient to secure a load for engine, by lengthening the adjusting pins until speed of engine is from 5 to 10 per cent. below normal.

After securing a more or less perfect adjustment of sensitiveness of the governor, as above, bring the engine up to speed by reducing the amount of lead in the holes in the governor, or the centrifugal weights. Begin by removing one-half the lead from the hole in each governor-weight which is farthest from the pin on which it turns, replacing the lead removed with a similarly shaped piece of hard wood to secure the remaining lead. The resulting change in speed of engine will give an approximate idea of how much should be removed to secure the desired speed, bearing in mind that removing lead from the holes in weights farthest removed from the pins on which weights turn will affect the speed three or four times as much as will a similar change in holes nearest these pins,

and that the same amount of lead should be kept in corresponding holes in each weight. It is intended that the engine should regulate well and be at proper speed with every hole in the weights about one-half filled with lead, but the effective stiffness of springs is quite uncertain, and the necessary amount of lead will vary to correspond. If, with all lead weight out, the speed is still too low with the governor sufficiently sensitive, one or more leaves must be added to each governor-spring, placing the added leaves between the longest leaf and the leaf next to it in each case.

Fundamental Principles for Regulating a Governor

To make a governor more sensitive, increase the tension in springs by lengthening the adjusting pins; to make it less sensitive, reduce the tension by shortening the pins. To increase speed of engine, remove lead weights from governor-weights; to decrease speed, increase the amount of lead in the weights.

These two principles should be studied carefully until thoroughly understood, as nearly all failures to successfully regulate a governor are caused by disregarding them.

In this connection, always remember that altering the sensitiveness by changing the length of adjusting-pins, also alters the speed of the engine. The speed should be brought back to that desired by a proper change in the amount of lead in the weights. Chang-

ing the speed by changing the amount of lead weights practically does not affect the sensitiveness.

Delay Dash-Pots

Engines designed for operating directly connected alternators in parallel are provided with patent delay dash-pots; otherwise the alternators will, under certain conditions, set up periodic cross-currents which may keep increasing in strength until the units are forced out of step. The delay dash-pot prevents this "surging" of currents with any generator not abnormally sensitive, but at the same time does not affect the regulation of the governor for actual change of load. As it is of the greatest importance to the proper action of these dash-pots that they be kept completely filled with oil, they should be filled every time the engine is shut down.

Directions for adjusting these patent delay dash-pots should be secured, if necessary, from the builders of each particular engine.

Operators often request information of the builders in reference to their left-hand or right-hand governors. The builders need some information from the operators before giving full instructions, and Figs. 21 and 22 show a cut of the data sheets they desire to have filled out. A study of these will enable the operator to give the data desired without first sending to the shops for such sheets.

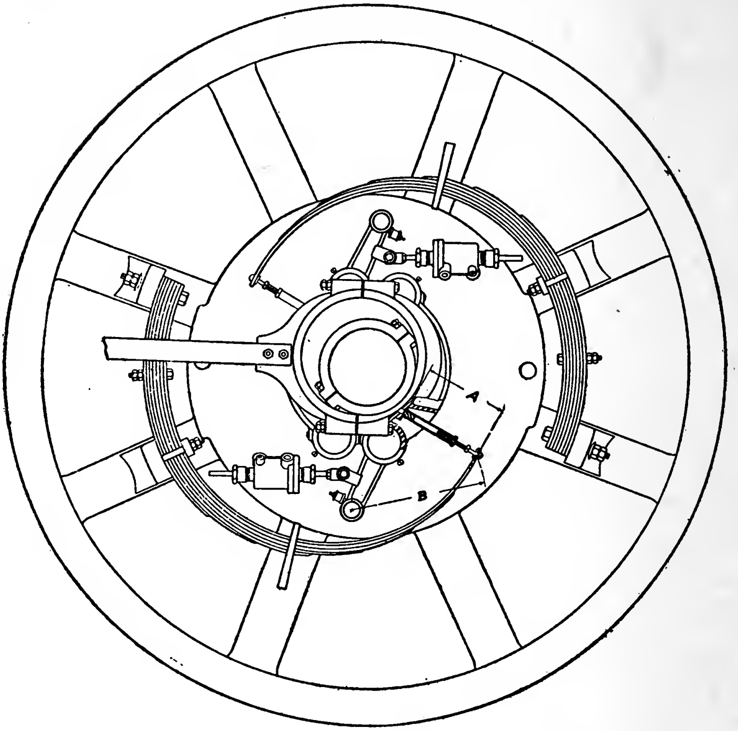

FIG. 21

SPEED....Revs. with no load. ||...Revs. with...H. P. ||...Revs. with....K.W.

PLAIN WEIGHT-ARM. SPEED CHANGER WEIGHT-ARM.

Sliding weight in....position.

No. of leaves in spring,.... No. of leaves in spring, ...

Lead weight in inner hole,.... in outer hole,.... Lead weight in outer hole, ...

*A............ †B......................... *A........†B.............

Remarks:...

....

....

Signed,..

Date...

NOTE—Plain governor weight-arm has two holes which hold lead weights for adjustment of speed. Outer hole is the one farthest from pin on which arm is pivoted. Speed changer governor weight-arm has no inner hole. In giving amount of lead weight in hole, state what proportion of hole is filled with lead, *i. e.*, "half full," "quarter full," etc. FILL OUT THIS REPORT AND RETURN TO SHOP AS SOON AS GOVERNOR IS ADJUSTED SATISFACTORILY.

*A = Length over all of adjusting-pin.

†B = Distance from center of weight pin to center of spring cup.

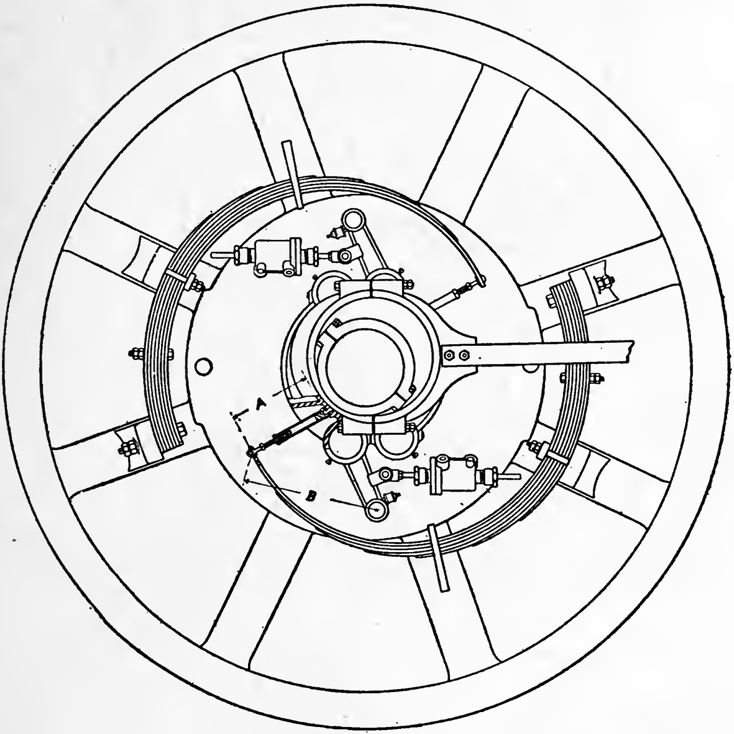

FIG. 22

SPEED...Revs. with no load. ||...Revs. with...H. P. ||...Revs. with....K. W.

PLAIN WEIGHT-ARM. SPEED CHANGER WEIGHT-ARM.

Sliding weight in....position.

No. of leaves in spring,.... No. of leaves in spring,.....

Lead weight in inner hole,.... in outer hole,.... Lead weight in outer hole....

*A.......... †B........................... *A........ †B.............

Remarks:...

....

....

Signed ....

Date...

NOTE.—Plain governor weight-arm has two holes which hold lead weights for adjustment of speed. Outer hole is the one farthest from pin on which arm is pivoted. Speed changer governor weight-arm has no inner hole. In giving amount of lead weight in hole, state what proportion of hole is filled with lead, *i. e.*, "half full," "quarter full," etc. FILL OUT THIS REPORT AND RETURN TO SHOP AS SOON AS GOVERNOR IS ADJUSTED SATISFACTORILY.

*A = Length over all of adjusting-pin.

†B = Distance from center of weight pin to center of spring cup.

IX

ROBB-ARMSTRONG-SWEET GOVERNOR

A CUT of the governor manufactured by the Ames Iron Works for use on their engines is shown in Fig. 23. This governor is placed in the second class and group

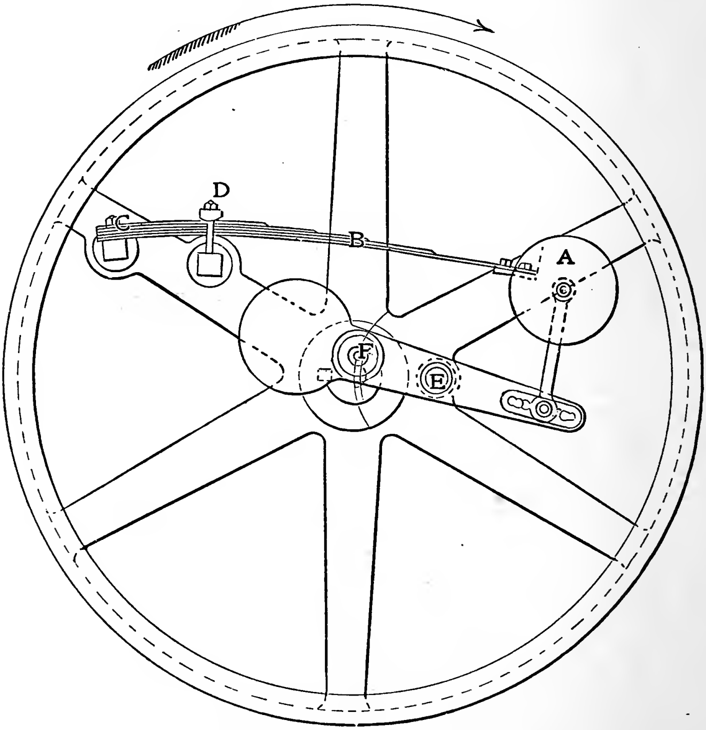

FIG. 23

in Chapter I. The weight *A* is fastened directly to the spring *B*, which is secured at *C*. The tension on the spring is changed by taking up or slackening the tension-studs *D*. The eccentric-arm is pivoted at *E*, moving the eccentric-pin *F*, which changes travel of valve and point of cut-off. The arm is actuated by the spring direct, by means of the one link *F*, one end of which can be changed in its position by shifting the pin into any one of the series of holes shown.

To increase speed, give more tension on the spring.

To decrease speed, give less tension on the spring.

To get closer regulation, and more sensitiveness, move the pin in the eccentric lever closer to the shaft-center.

To make more sluggish and put a stop to racing, move the pin in the lever toward the rim of the wheel.

No change of weight is provided for, as the above allowance for change is considered by the makers to be sufficient to cover all requirements.

X

THE FITCHBURG STEAM-ENGINE GOVERNOR

The type of governor shown in Fig. 24 is in the second class of the first group of Chapter I, and is of the patent and manufacture of the Fitchburg Steam-Engine Company, used on all engines of their make.

The small weights shown are to counterbalance the weight of valves, stems and eccentric, and are not to be considered in the adjustment of the governor. The weights *A, A* are changeable. *Adding weight* decreases speed, and *taking it away* increases it. The weight-arms are pivoted at *B, B,* and are opposed by the springs *C, C,* which are attached, as shown, directly to the weights.

Tightening the springs, increases speed and sensitiveness.

Slackening springs, decreases speed and sensitiveness.

These engines are so carefully adjusted in the shops as to require little change of weight. The principal changes for speed and sensitiveness are to be made on the springs.

To get more speed, tighten the springs.

To lessen the speed, slack off on springs.

To get more sensitiveness, increase tension on springs;

or, if speed is already attained, increase the tension and weight at the same time to keep the speed at the same point.

To make more sluggish, decrease spring-tension, and

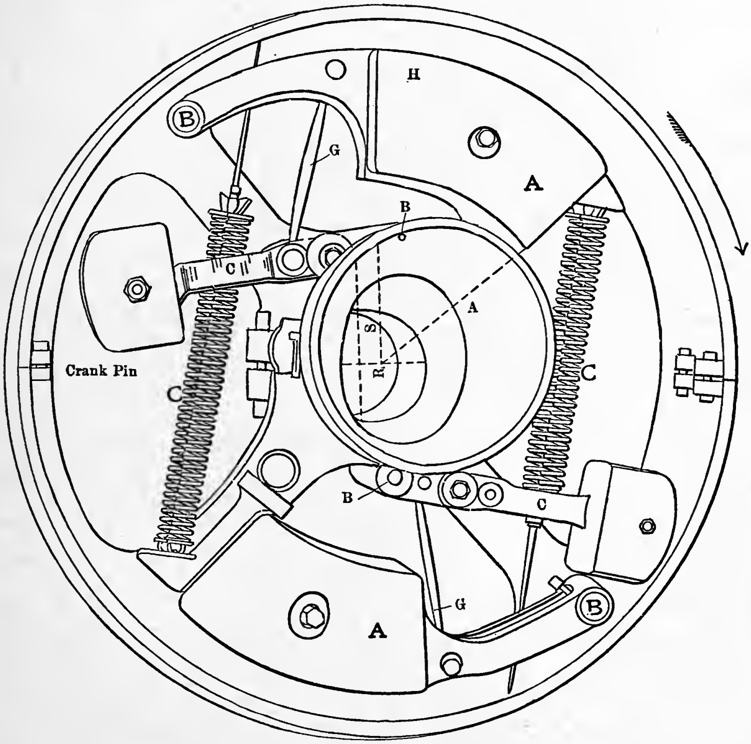

FIG. 24

if speed is right, decrease weight also to keep the speed at the same point.

As correct valve setting is necessary to good regulation, the following extract from the builders' instructions as to how to locate the governor-case on the shaft will be of service.

The location of the governor-case is determined by placing the engine on one dead center and rolling the case around the shaft until the offset of the eccentric is on the opposite side of the shaft from the crank-pin. Then roll carefully into such position that when (with the springs removed) the eccentric is thrown back and forth across the shaft, no end motion is given the valve-rod. At this place tighten the governor-case firmly upon the shaft and turn the engine to the opposite dead center, and again move the eccentric back and forth across the shaft. If there is at this end any end motion to the valve-rod, change the position of the governor-case on the shaft enough to make the motion just half as much, then fasten the governor-case firmly in this final position by drilling into the shaft for the point of the set-screw and then tightening the clamp-bolts to place solidly. Put in the springs and tighten them until the proper number of revolutions is obtained. Be sure to tighten up those that go through the counterbalance which hangs nearest the springs (when the governor is at rest) about three-fourths of an inch more than the springs on the other side.

When it is desired to change the direction of rotation of a Fitchburg engine a new eccentric must be procured from the makers and put on in place of the one on the governor.

The ends of the links which connect the weight-arms must be changed, on the counterbalance weight-arm end, to the holes opposite those which they occupied in the old eccentric.

XI

THE AMERICAN-BALL BALANCED AUTOMATIC GOVERNOR

Herewith is illustrated a new type of fly-wheel governor, manufactured by the American Engine Company, of Bound Brook, N. J., and with which the American-Ball engines are now equipped. It is the outcome of redesigning the Ball balanced automatic governor.

In the new type, Fig 25, two features are embodied, one being the method of establishing a gravity balance, and the other the arrangement and relation of the springs, of which there are two. A second arm is provided in the governor, as shown in Figs. 26 and 27, which is so pivoted that its center of gravity practically coincides with the center of the shaft, and therefore cannot develop centrifugal force. The arm *B* is pivoted at the most desirable point for determining the path of motion of the valve-actuating pin, the second arm *B* being so connected to the centrifugal governor that the gravity of one is always opposed by the gravity of the other at every position of the governor-wheel. By this arrangement the centrifugal force of the governing-arm, under the control of the spring, governs the engine, and the disturbing

gravitation of the arm is balanced by the opposing gravity of the second arm, which has practically no centrifugal force.

Attention is especially directed to the arrangement of the double springs for the prevention of the trouble-

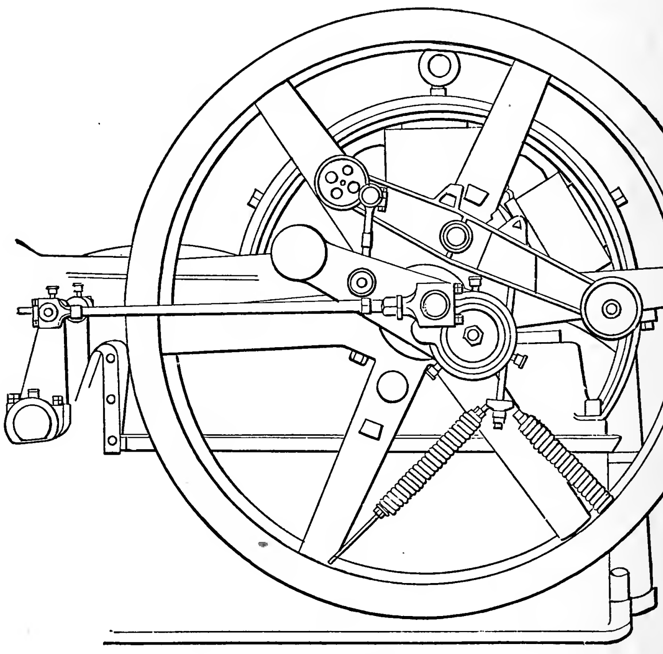

FIG. 25

some swaying characteristic of a single spring, when used, due to the centrifugal force and gravitation. These springs are convenient for slight adjustments for the difference in speed at the several points of cut-off.

Should the speed decrease under load more than is desirable, this fault may be corrected by slacking the

spring *C* and tightening the spring *D* which makes the governor more nearly isochronous. On the other hand, if the action of the governor is unstable, slacking the spring *D* and tightening the spring *C* will correct it.

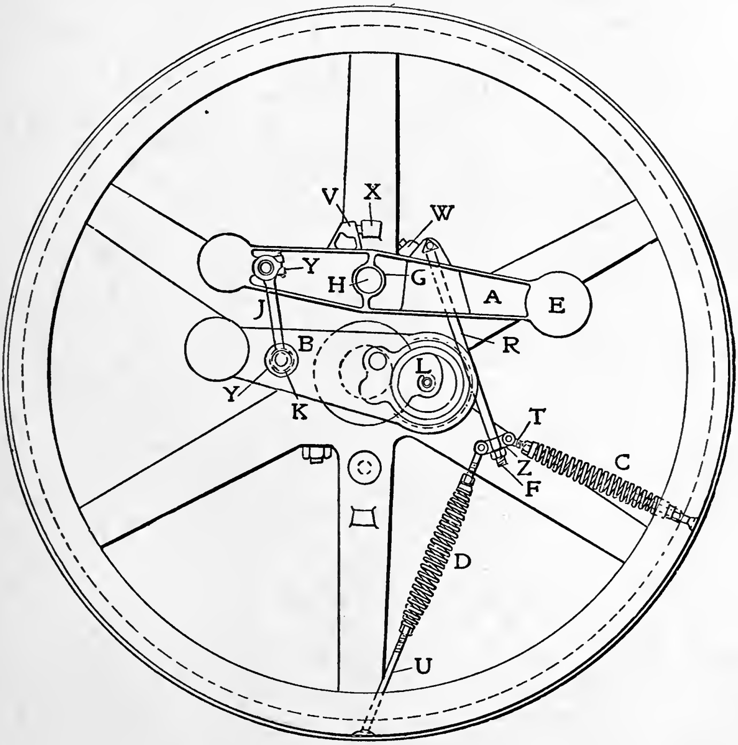

FIG. 26

For slight changes of speed, the nut *F* may be tightened or slacked, but for a considerable change of speed it is necessary to add to or take from the weight in the pocket *E* of arm *A*.

In Figs. 28 and 29 are shown the parts of which the governor is composed. It will be seen that the gov-

ernor-weight or arm *A* is provided with a brass bushing *G*, in which three oil grooves are cut which permit of freely lubricating the steel-governor weight-stud *H*. The arm *A* is connected to the eccentric carrier arm *B*

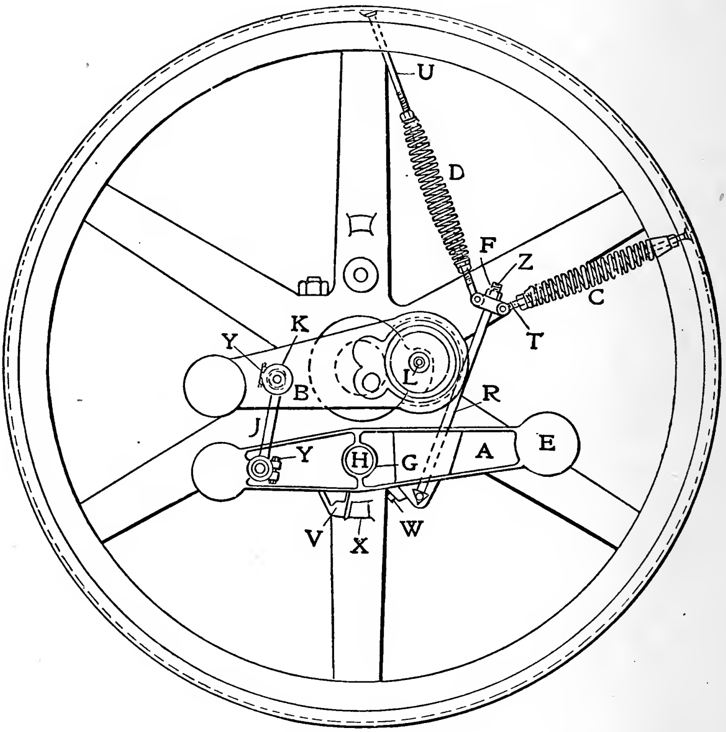

FIG. 27

by means of the governor link *J*, which is fitted with graphite bushings *K* and held in place by the governor link-pin *L*. The eccentric carrier arm is fitted with a cast-iron bushing *M*, which is quite suitable, there being so little movement at this point that a bushing of special material is unnecessary. At the

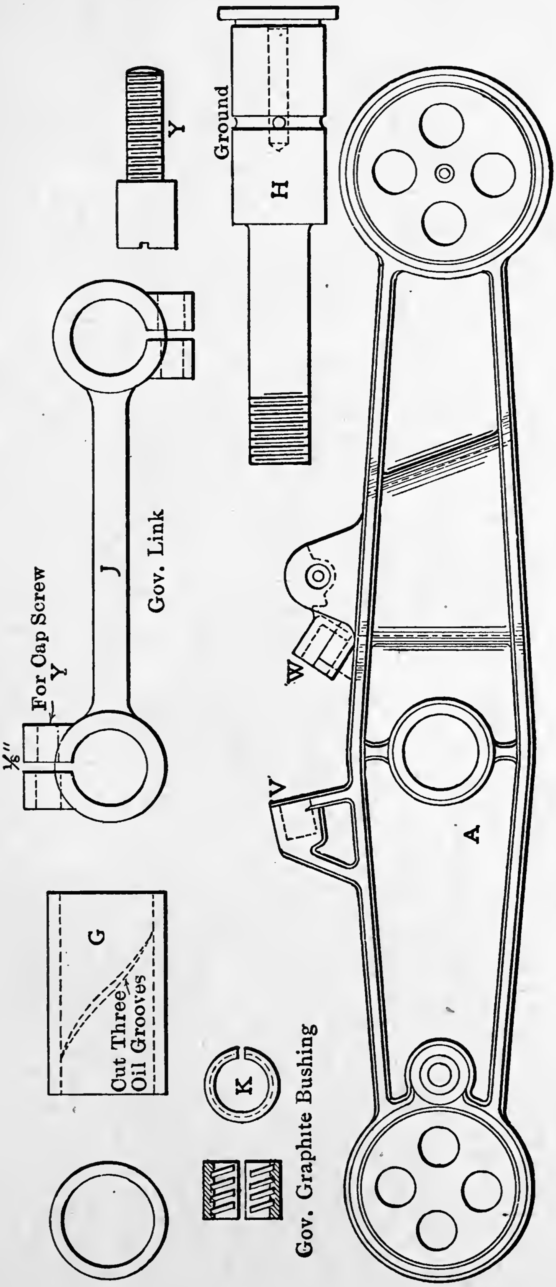
Y
Ground
H
For Cap Screw
Y
1/8"
J
Gov. Link
G
Cut Three
Oil Grooves
K
Gov. Graphite Bushing
W
V
A

FIG. 28

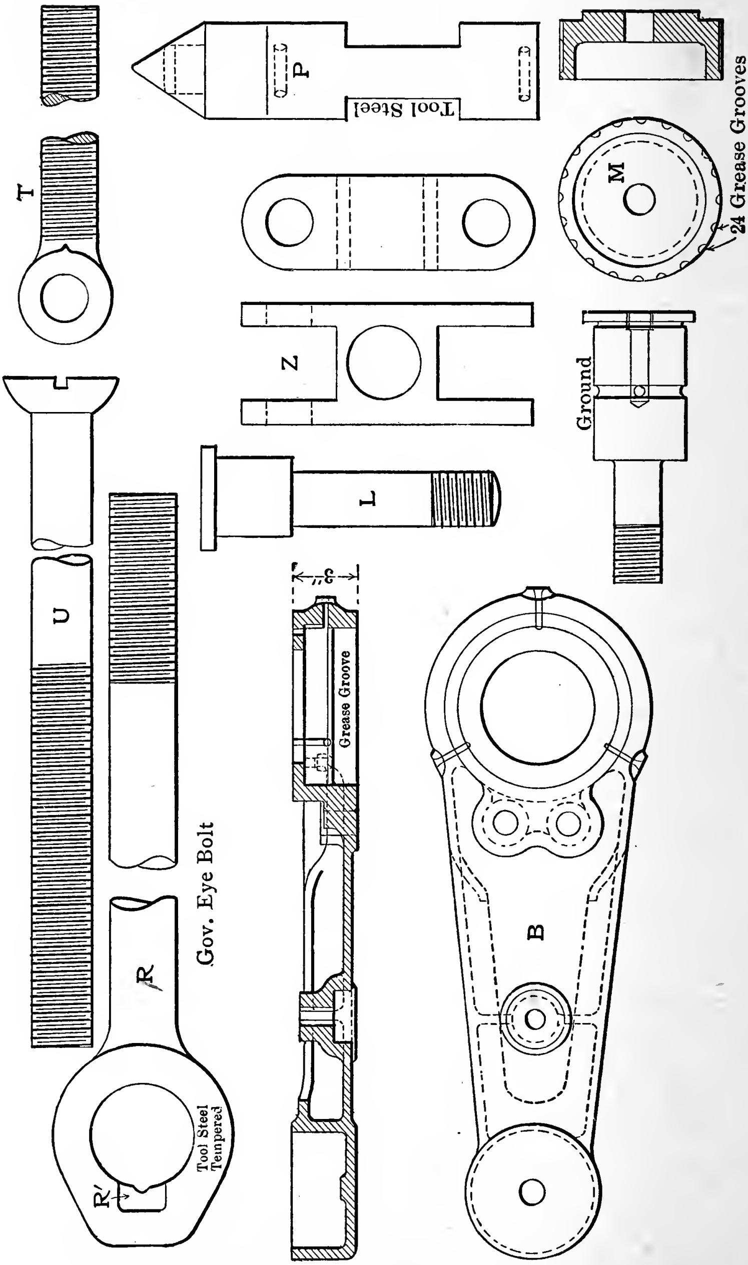
T
P
Tool Steel
M
24 Grease Grooves
Z
Ground
L
U
Grease Groove
B
Gov. Eye Bolt
R
R′
Tool Steel Tempered

FIG. 29

point *O* in the boss on the arm *A*, a tempered knife-edge *P* is inserted. Three notches are filed in the hole so that the knife-edge will fit snugly and not turn. On this knife-edge is suspended the governor-spring eye-bolt *R*, in the eye of which is fitted a piece of tempered tool-steel at R^1, which wears on the tempered knife-edge. This eye-bolt is threaded at the opposite end, over which is fitted the governor-screw spring-clip *Z*, which is held in place by a nut and lock-nut. The springs *C* and *D*, Figs. 26 and 27, are screwed into the spring-eyelet *T* at one end and the spring-screw *U* at the other.

The arm *A* has two lugs cast on it at *V* and *W*, in which are fitted a piece of round fiber, which, coming in contact with the lug *X* on the governor-wheel, fixes a limit to the movement of the arm *A*.

These governors are made for engines running over, unless ordered otherwise, although provisions have been made for permitting of changing to governors running in the opposite direction. If, for instance, an engine were equipped with a right-hand governor so that it ran over, and it was desired to operate the engine in the opposite direction, it would be necessary to drill holes for the arrangement of the proper pins and springs as shown in Fig. 27. The position of the governor would then become reversed and the engine would operate in the reversed direction.

XII

CURTIS STEAM TURBINE GOVERNORS

The General Electric Company, in the manufacture of the Curtis Turbine, uses a governor of the spring-loaded fly-ball type on the main shaft, and necessarily operating at the same speed without the introduction of intermediaries. The movement of this governor actuates the device controlling the valves admitting the steam to the turbine. The assembly of these turbines with the governor at 17 and the valves it controls at 18 is shown in Fig. 30. A detail view of this governor is shown in Fig. 31. A certain percentage of the spring effect is carried in a small spring under the control of a motor operated from the switch-board, for the purpose of varying the speed of the turbine in order to synchronize with other machines.

Referring to this figure the following is a list of the various parts of a

Maine Turbine Governor

1. Governor bracket.
2. Stud for frame.
3. Middle plate.
4. Top plate.
5. Nut for lower end of stud — with lock washer.
6. Nut for upper end of stud — with lock washer.
7. Strap for studs.
8. Bolt for strap — with nut and locker washer.
9. Fulcrum block.

10. Guide roller block.
11. Bolt for fulcrum and roller blocks — with nut and lock washer.
12. Guide roller — with pin and cotters.
13. Governor weight.
14. Knife-edge block — with screws.
15. Hook — with screws.
16. Plug for balance pocket.
17. Yoke for links.
18. Links.
19. Universal joint.
20. Lower governor plug.
21. Upper governor plug.
22. Governor spring.
23. Key for upper plug with screws.
24. Adjusting nut for upper plug.
25. Connection rod.
26. Gimball transmission bearing.
27. Ball races for Gimball bearings, upper and lower.
28. Gimball pivot — for box.
29. Gimball pivot — for beam.
30. Bushing for pivots.
31. Gimball ring.
32. Beam.
33. Dome — with bolts.
34. Cover plate for dome — with cap screws.
35. Bearing bracket for dome — with bolts.
36. Spindle for roller bearing.
37. Rollers for bearing. (Number.)
38. Bushing for bearing.
39. Pin for attaching synchronizing connection to beam.
40. Connection for synchronizing spring.
41. Upper plug for synchronizing spring.
42. Synchronizing spring (give dia. spring, dia. wire, active turns).
43. Traveling nut for synchronizing spring.
44. Limit switch.
45. Synchronizing motor (Series d. c. — Give rating).
46. Worm for synchronizing gear.
47. Bracket for worm.
48. Worm wheel.
49. Cap for synchronizing screw.
50. Synchronizing screw
51. Bracket for synchronizing gear — with bolts.

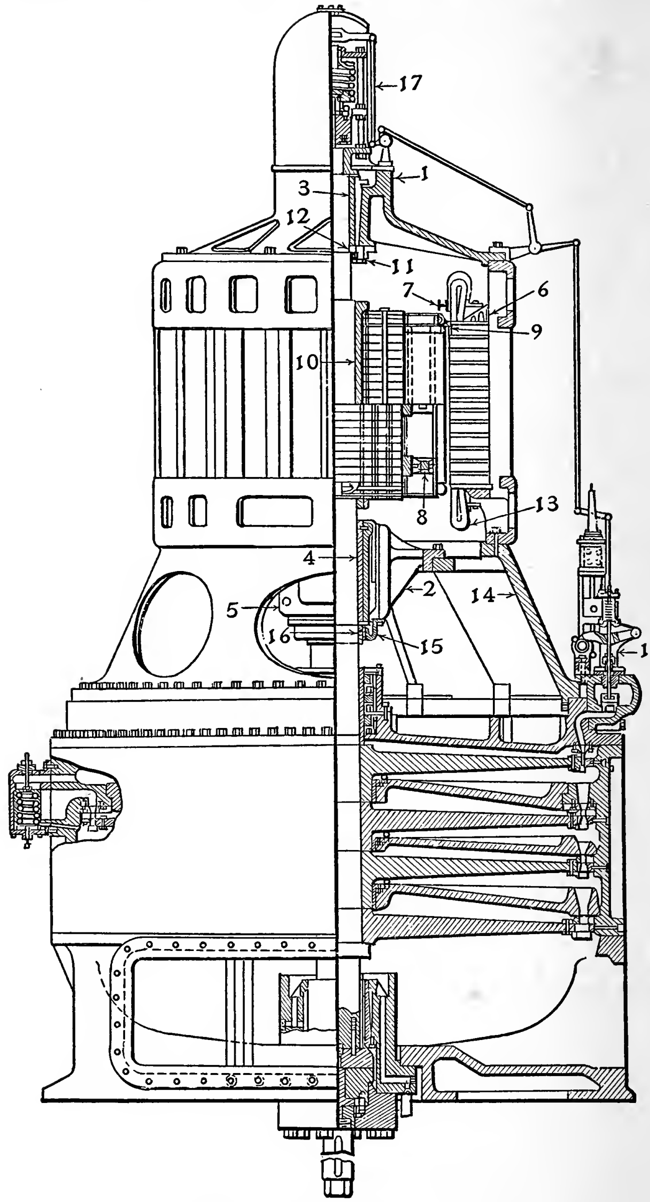

FIG. 30

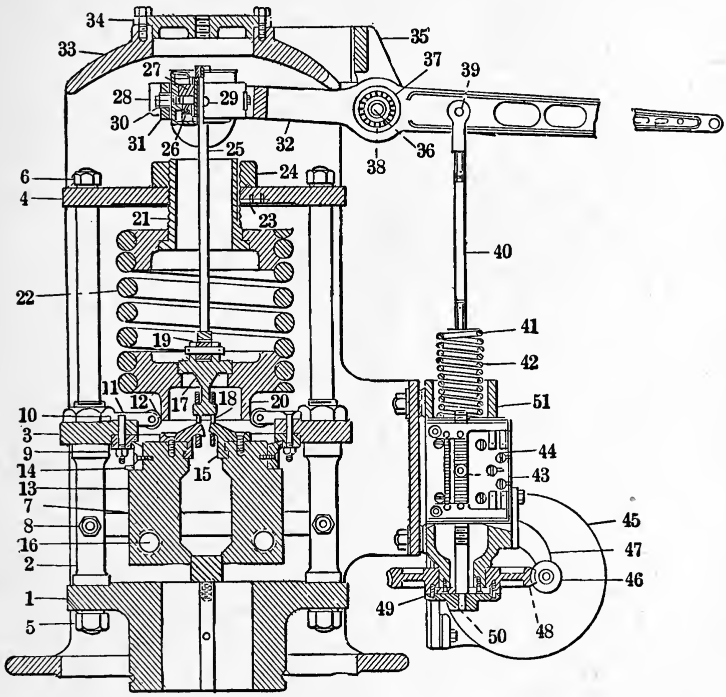

FIG. 31

Operation of Governor Explained

By referring to Fig. 32 the following explanation of the governor-action will be made plain.

The governor-bracket, holding the weights and spring, revolves with them and the shaft. The shaft extends up through the bracket at *H*. The spindle *C* revolves with the bracket and swivels in the end of the beam, which is stationary. The motion of this beam is transmitted through the rod *D* (Fig. 33) to the arm *G* and to the pilot valve of the oil cylinder *B*, containing the piston *A*, which actuates the main arm. The

main arm transmits the motion, either by means of a rack connecting with a pinion or by means of cranks, to the rod carrying the cams. These cams act directly

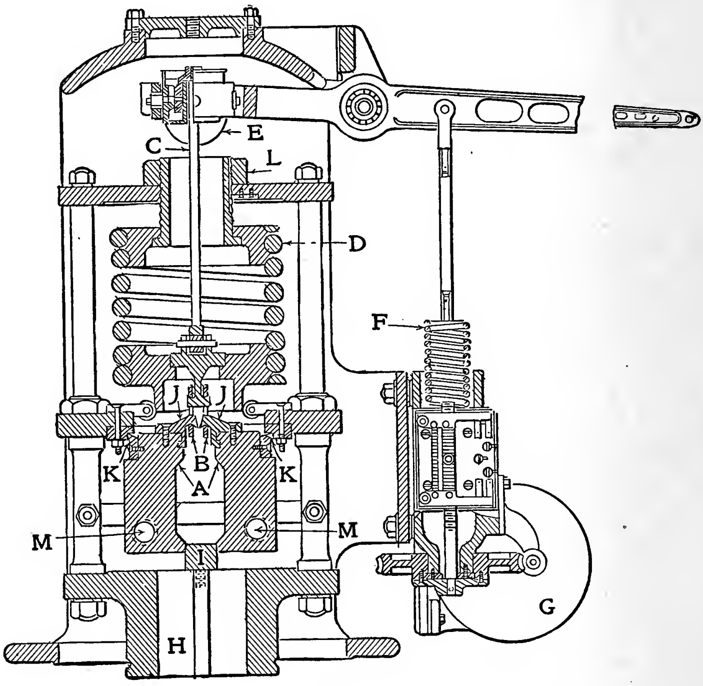

FIG. 32

on the valves, opening and closing the number called for by the condition of the load.

In Fig. 32 the governor is shown at rest, in position for full admission of steam to the turbine. The weight rests on the stop *I*, which corresponds to the inner stop of the weights of a shaft governor. The weights are fastened over a knife-edge to the links at *J*, *J*, and have their fulcrum over the edges *K*, *K*. The links hold to the yoke in the bottom of the spring,

and the other end of the spring is fastened to the top plate by means of the plug and adjusting nut. The weights act centrifugally, and as they fly out from

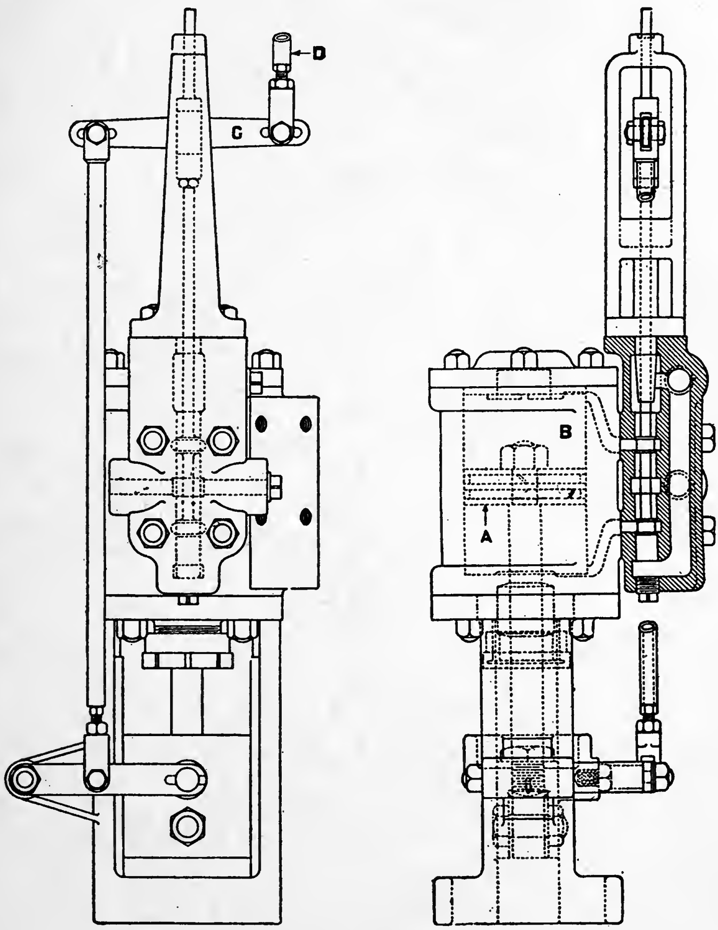

FIG. 33

the center they push against the edges *K*, *K*, and pull against the edges *J*, *J*.

With this governor as with shaft-spring governors,

tightening the spring increases speed, and slackening it, decreases the speed. To tighten the spring of this governor screw down on the adjustment nut *L* (Fig. 32), to slacken the spring, slack off on the nut.

To increase the sensitiveness or decrease the regulation of this governor, increase the number of working coils in the main spring, keeping initial tension the same.

To make the governor less sensitive, or increase the regulation, decrease the number of working coils in the main spring.

For the purpose of changing the regulation through a small range, the weights are provided with pockets for loading. Increasing the weight decreases the regulation and vice versa. Any change in the weight requires a corresponding change in the initial tension of the main spring in order to maintain the proper speed.

XIII

CHANGING THE SPEED OF PENDULUM GOVERNORS*

An old engine was brought to a machine-shop to be thoroughly repaired. When it was nearly ready to set up the question of its future speed was presented, and it was decided to run it 65 revolutions per minute. An engineer who had had charge of this engine several years before was consulted, and he reported that its former speed was 75 revolutions per minute. From this fact, in connection with measurements made to determine the diameter of pulleys used to drive it, the speed of the governor was calculated, and as all men in charge of plants do not understand the principles involved in this and similar problems, an explanation of the same will be given in a practical way.

A governor, as used to regulate the ordinary Corliss, or any similar type of engine, is illustrated in Fig. 34. In the case already referred to, the crank-shaft revolved 75 times per minute, and the pulley on it is 9 ins. in diameter (see 2 in the cut). The governor pulley 3 is 12 in. The speed of governor is $75 \times 9 \div 12 = 56$ revolutions per minute.

On some of the governors furnished to users the

* Contributed to *Power* by W. H. Wakeman.

speed is stamped, which is a great convenience; otherwise, it is necessary to determine experimentally the speed required to elevate the balls to their working plane.

The working engineer is often confused in regard to changing the speed of engines, because he fails to fix in his mind the fact that when the speed of a governor

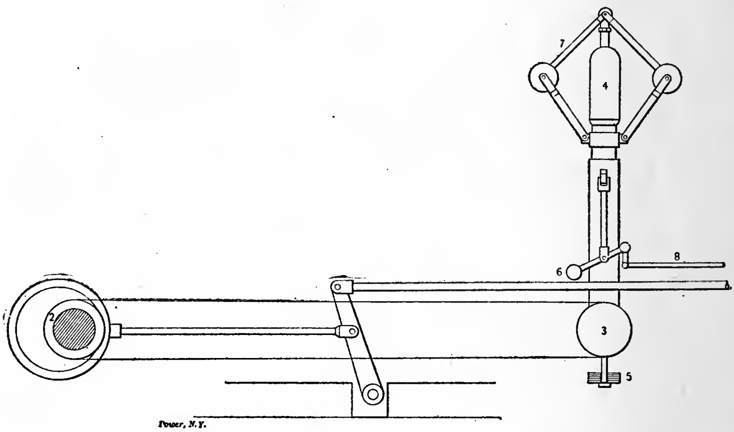

FIG. 34

is once fixed it remains unchanged, regardless of any change made in the size of pulleys used to drive it.

In a swinging-pendulum governor the centrifugal force and gravity are equal at one point only in its operation. The force of gravity is represented by the weight of the balls, and when they revolve fast enough for the centrifugal force to equal the weight the two forces are equal. The point where the two forces are equal, or nearly so, is fixed, so that when the balls are raised to the working plane by centrifugal force the governor mechanism is cutting off the steam

at its minimum point. For that reason the same speed of governor must be maintained as an increase or decrease of engine-speed hastens or delays the cut-off action beyond the proper point. If driven a little too fast, it reaches its highest plane and shuts off steam altogether; if a little too slow, it falls to its lowest plane, admitting the maximum quantity. If extra weights are added to or taken from the governor, if the tension of a spring is increased, or decreased, or the reach-rods on a Corliss engine are changed, the speed at which a governor must be driven to be kept within its operative plane will be affected, but this belongs to another part of a subject that will receive attention later.

The governor referred to revolves 56 times per minute and it is desired to run the crank-shaft 65 revolutions in the same time. Multiplying the speed of crank-shaft by the diameter of pulley 2 and dividing by the speed of governor shows that the pulley 3 should be $65 \times 9 \div 56 = 10.4$ in. in diameter.

Where the pulley 3 is to be retained and a smaller one put on the crank-shaft, the speed of governor is to be multiplied by the diameter of pulley and the product divided by the speed of crank-shaft. Then $56 \times 12 \div 65 = 10.3$ in.

Where a governor is driven by gears the same principle is involved, but some engineers do not understand it so, therefore an illustration will be given.

Figure 35 shows a governor driven from the crank-shaft by gears. Here 2 represents a gear on the crank-shaft, which drives another gear 3 on an independent stud. The latter is twice as large as the

former and the bevel gears 4 and 4 are alike, therefore the side shaft 5 makes one revolution while the crank-shaft gear 2 revolves twice.

The first two years that this engine was used it revovled 50 times per minute. The bevel-gear at 6 has

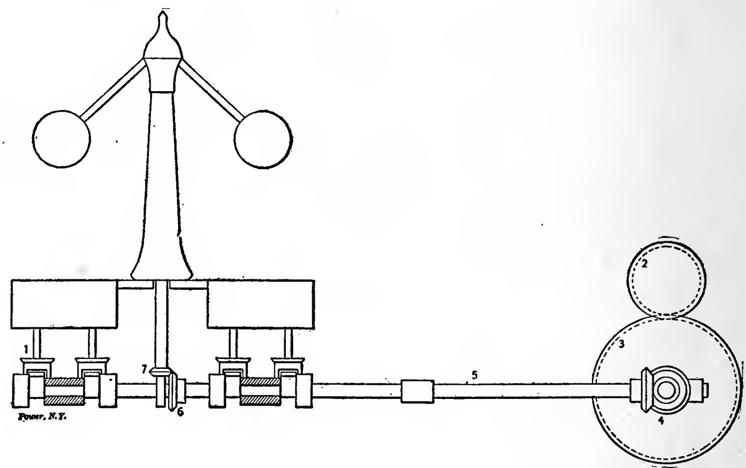

FIG. 35

44 teeth and 7 has 20, therefore the speed of governor is $25 \times 44 \div 20 = 55$ per minute.

Suppose, for example, that the 20 gear at 7 be taken off and a 30 gear be put in its place, how fast will the governor run? Some may figure it at $25 \times 44 \div 30 = 36.7$ times per minute. It has been done so, yet it is not correct. The speed of the governor remains constant; it is the speed of the engine which may be changed.

This governor revolves 55 times per minute; the new gear at 7 has 30 teeth, and 6 has 44, therefore the speed of side shaft 5 is $55 \times 30 \div 44 = 37.5$ revolu-

tions per minute. While 5 makes one turn 2 revolves twice, therefore the speed of engine should be $37.5 \times 2 = 75$ revolutions per minute. If this reasoning is correct (and as a careful count of the speed shows it to be 75) it proves the theory to be right.

Other means adopted for changing the speed of engines require a passing notice in order to cover the subject. If the center-weight 4, in Fig. 34, is made lighter it will decrease the speed of both engine and governor, and if made heavier it will increase the same, because it will change the plane in which the balls travel for a given speed. Some governors have hollow center-weights, so that shot can be put in or taken out at pleasure. Any change in the weights at 5 will have the same effect, as the rod which supports them is a continuation of the spindle and collar which carries 4.

This is a very convenient plan for use in connection with a governor that does not respond quickly to changes in the load; for, when a heavy machine is started up, another weight may be added at 5, and when said machine is stopped the weight may be removed. This is a crude plan when compared with modern regulating devices, but it has been found to be much better than none.

The disk 6 is on a lever, and as it is moved nearer to or farther from the fulcrum it changes the speed slightly. Some governors are adjustable at 7, so that by changing the length of arm at this point, the speed is changed. The reach-rod 8 may be made longer or shorter, thus making small changes in the speed; but neither this nor the plan just preceding it is recom-

mended, as they are not founded on desirable principles, and bring objectionable features into the matter which it is well to avoid. When a governor with its connection is properly set up, it is not advisable to change either 7 or 8, for changes in the former may affect the sensitiveness of the mechanism, and careless adjustment of either may prevent a very short cut-off, and thus cause trouble in case all of the load is suddenly thrown off.

Some Causes of Trouble with This type of Governor

In almost all makes of these governors there is a pin on which the weights are brought to rest when the mechanism is not in action. This is a safety-pin, or sometimes a collar, which prevents the mechanism from falling so low that no steam will be admitted. This pin, or collar, is so placed that when the engine is at rest it will get steam. When the engine is in full operation the pin is removed or the collar so turned that, should the belt or gear break, the mechanism would drop so low as to cut off all steam and a shut-down results.

In plants where heavy and changing loads are handled, it is not uncommon for one to come on so heavy as to make the mechanism drop low enough to shut off steam, if the operator has attended to his duty of removing the pin or setting the safety collar after starting up. The result is a shut-down, and it may confuse the inexperienced operator till the lesson is

learned and he knows the cause. Always look at the "safety" when a shut-down occurs out of the usual time.

Some governor pulleys are secured to the shaft with a set-screw which may come loose, or a key even may work loose. The pulley may hold just enough to slowly rotate the governor but not fast enough to bring it up to speed. The result will be a runaway engine. An oily or slack governor-belt may also cause this.

The following experience illustrates another cause of trouble with governors.

On a 14 x 36 Corliss engine of from 90 to 140 H. P., an overload would cause the steam to follow full stroke, as the steam-valves would not trip and cut-off. The governor, after going down until the tripping cams did not touch and trip the latches, would have a hard struggle to rise again to a point where the tripping would recommence. It seemed that the force required to trip the latches was so great that the engine speed necessary to give the governor the needed power had to be greatly accelerated, and in going through this part of the performance the governor would dance violently with every movement of the trip-rods. These conditions produced racing, or rather, "hunting."

The latches, or hook-plates, had a catch surface of $\frac{1}{8}$ of an inch and tripped very stiffly. Thicker leathers were placed in the hooks, so they did not overlap the plate on the valve-crank so far, reducing the catch surface to $\frac{1}{16}$ of an inch. At present the governors are doing their work satisfactorily, but during two and a

half years the corners have been worn completely off the latches and blocks five times. Of course this is due to the very small amount of catch surface allowed. The blocks and latches are as hard as any, but the decreased area of contact, with increased pressure on the plates, causes the increased wear. This is the sacrifice necessary to get earlier cut-off and greater steam economy. This is a case where the strain on catch-blocks must be reduced to assist the governor in its work.

INDEX